BUILDERS OF MODERN INDIA

Chandrasekhara Venkata Raman

P.R. Pisharoty

PUBLICATIONS DIVISION

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C.V. RAMAN

P.R. PISHAROTY

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About the Series

The objective of the series is to record, for the present and future generations, the story of the struggles and achievements of the eminent sons and daughters of India who were instrumental in our national renaissance and attainment of independence. Except in a few cases, such authoritative biographies are not available.

The series is planned as handy volumes written by knowledgeable people, giving a brief account, in simple words, of the life, time and activities of these eminent leaders. The volumes do not intend either to be comprehensive studies or to replace the more elaborate biographies.

About the Author

P R. Pisharoty was Professor Emeritius at the Physical Research Laboratory, Ahmedabad. He was a student of Professor C. V. Raman, who once recorded: "I would include Mr. Pisharoty in a short list of the ablest men who ever worked with me." After serving as a Lecturer in Loyola College, Madras for about a decade, he became, an Officer of the India Meteorological Department in 1942. He obtained his Doctorate in Meteorology from the University of California in 1954. After superannuation in 1967, he joined the Physical Research Laboratory, as a Professor. He has held important positions like the Director, Institute of Tropical Meteorology, Pune, Director, Remote Sensing and Meteorology Division of the Space Applications Centre, Ahmedabad.

Dr. Pisharoty, Padamshree served on several International Scientific Bodies with more than a hundred scientific papers to his credit.

Preface

It is a privilege to be a biographer of my teacher Chandrasekhara Venkata Raman. I, therefore, readily agreed when the Director of the Publications Division invited me to undertake the task of writing a biography of C.V. Raman, under the series "Builders of Modern India", Raman has been the greatest figure India has produced in the area of Scientific Research. It may be recalled that he was India's first Bharata Ratna in Science.

Some diffidence set in as I write. However, it was removed by Kalidasa's *sloka** in *Raghuvamsa,* which says that the task has been simplified by previous writers and now it is akin to stringing of pearls already pierced by diamond drill.

Professor S. Bhagavantam has written a comprehensive article on Raman for the Royal Society, London, which has been published in the Society's series: *Biographical memoirs of Fellows* for 1971. The Andhra Pradesh Akademi of Sciences, published a book in 1972 entitled: Professor Chandrasekhara Venkata Raman, by S. Bhagavantam. *Bhavan's Journal,* Vol. XVII, No. 11, (December 1970), published a number of articles on Raman. *Current Science,* Vol. XL, No. 9. (May 1971) is a Raman Memorial issue.

Dr. L. A. Ramdas has written two informative articles on Dr. C.V. Raman in the *Journal of Physical Education.* Professor S. Ramaseshan gave the first *C.V. Raman Memorial Lecture* at the Indian Institute of Science, on March 3, 1978, which has since been published. There are also the numerous papers and lectures by Professor Raman himself. I have liberally drawn from these sources and I am grateful to them.

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* अथवा कृत वाग्द्वारे वंशेस्मिन् पूर्व सूरिभिः
मणौ वज्र समुत्कीर्णे सत्रस्येवास्ति मे गतिः

I had also the unique opportunity of discussing the various aspects of Raman's life and work with Professor K.R. Ramanathan, the most distinguished student and collaborator of C.V. Raman. The Raman Research Institute, Bangalore has a Raman Museum to which I was given free access by the authorities of the Institute. In this biography I have just strung together the numerous pearls available from all these sources. I am deeply indebted to all of them.

Professor Raman was a self-made man. Gifted with a keen intellect, through persevering hard work and an indomitable will, he rose to great heights in the world of science and in 1930 won the Nobel Prize for Physics. I have tried to present the story of Raman, the man, the teacher and the scientist, so that it may act as a source of inspiration to the young men and women of our land. In one of his speeches Raman said:

> "The quality of the Indian mind is equal to the quality of any Teutonic, Nordic or Anglo-Saxon mind. We have, I think, developed an inferiority complex. What is needed in India today is the destruction of that defeatist spirit. We need a spirit of victory, a spirit that will carry us on to our rightful place under the sun, a spirit which will recognise that we, as inheritors of a proud civilisation, are entitled to a rightful place on this planet. If that indomitable spirit were to arise, nothing can hold us from achieving our rightful destiny."

I shall feel amply rewarded if at least some, if not all, of the young readers of this short biography will be fired by Raman's spirit of achievement.

Ahmedabad

April 28, 1981

P. R. Pisharoty

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I

Introduction

Professor Chandrasekhara Venkata Raman has been a great *Acharya.* He created new knowledge, imparted knowledge to others, and nurtured young minds so that they would grow up to create new knowledge as well as spread a scientific culture. During a scientific seminar in which Professor Raman was present, a distinguished scientist was referred to as one who could say the *last word* on a particular subject. Professor Raman jumped up and said that he would prefer to say the *first word* on a subject. And that is exactly what Professor Raman did in several scientific fields–optics, x-rays, ultra sonics, human vision, etc.

Books on history, have been mostly records of kings and their reigns or of their political counterparts–Presidents and Prime Ministers. Most of the events which had a profound influence on society have to be inferred indirectly through literary writings like dramas and novels of the different periods. Professor Raman had a unique ability to build up the mind and spirit of scientific personnel in India, during a period when it was badly required. His efforts could be fully appreciated by a grateful nation, only when the development and management of science in India had to be shouldered by Indian Scientists on the attainment of Independence. Thus Professor Raman is truly one of the most important Builders of Modern India.

Born on November 7, 1888, at Thiruvanaikkaval, a small village about 5 kilometres north of Tiruchirappalli in South India, of parents belonging to the lower middle class, precocious Raman matured into an internationally great scientist through sustained hard work. He won the coveted Nobel Prize for Physics in 1930,

for the discovery of an Optical Phenomenon, later known as the Raman Effect. He had served as an able officer of the Indian Financial Service for about ten years before 1917, when he opted for full time scientific work.

In 1933 Professor Sir C. V. Raman, Nobel Laureate, accepted the position of Director and Professor of Physics, Indian Institute of Science, Bangalore. In 1948, he retired from the Indian Institute of Science and established a Research Institute at Bangalore itself, built mostly from his own personal funds including the Nobel Prize money. He worked at his Institute till his death on November 21, 1970. His *Samadhi* is located within the compound of the Institute.

This Institute is now known as the Raman Research Institute (RRI), Bangalore. In founding it Professor Raman wrote: ".... It is my earnest desire to bring into existence a Centre of Scientific Research worthy of our ancient country where the keenest intellects of our land can probe into the mysteries of the Universe and by so doing help us to appreciate the transcendent power that guides its activities. This aim can only be achieved if by His Divine Grace, all lovers of our country see their way to help the cause".

May the Institute and the scientists of our country fulfill the wish of Professor Chandrasekhara Venkata Raman, and thereby bring greater glory to this ancient land.

II

Parentage

Tamilians believe that talent and culture naturally come to those who drink Cauvery water. It simply reflects our ancient riverine culture. Cauvery is as sacred to the South Indians as Ganges is to the North. The ancestors of Raman were inhabitants of the Cauvery delta.

The family of Raman traces its descent from one Ayyamuthian. By his own enterprise and efforts he had acquired about 200 acres of wet lands in the villages Mangudi and Porasakudi in Tanjore District. Ayyamuthian had two sons Vengappan and Amridappan, among whom the landed property was divided. They lived as agriculturists. Amridappan's youngest son, born in 1837, was Ramanathan, Raman's paternal grandfather. A scholar in Tamil and religious, he was also an agriculturist.

Chandrashekharan, Raman's father was born in 1866 as the second son of Ramanathan and Sitalakshmi Ammal. The elder son did not survive beyond the age of two or three years.

Chandrashekharan spent his student days in the Town School at Kumbakonam. It was about twenty kilometres from the village of Porasakudi, to which his father had shifted from the village Mangudi, soon after Chandrashekharan was born. The boy passed his matriculation examination in 1881.

Soon thereafter he married. The bride was Parvati Ammal, second daughter of Saptarshi Sastriar of Thiruvanaikkaval, a suburb of Trichinopoly (Tiruchirapally), in the island of Srirangam. This Saptarshi Sastriar was a great Sanskrit Scholar. In his inordinate zeal to study Nyaya he in 1846 at the age of fifteen trekked all the way from Tiruchirapally to Nadia in Bengal and returned on foot

after a year or so. Thus Raman has a distant connection with Bengal through his maternal grandfather. Perhaps he has also inherited his thirst for learning and scholastic aptitude from Saptarshi Sastria through his mother. It may be of some interest to note, that the custom in those days was to pay money for the bride–*Varasulkam*– by the bridegroom's party. Probably it was a good custom; certainly it avoided all the problems of the present dowry system, in which the bridegroom's party expects money from the bride's parents.

Chandrashekharan passed his First Year Arts (F.A.) Examination, after a two-year course, from S.P.G. College, Tiruchirapally. He spent the next two years at the Madras Christian College, undergoing the course for his B. A. Degree Examination, Apparently he did not obtain the degree. However, he was enterprising enough to start a Lower Secondary School as Tiruvadamaruthur, a few miles off Kumbakonam. He worked there for about two years. Thereafter he shifted to Tiruchirapally, and joined as a pupil teacher at the High School classes of the S.P.G. College, where he had been a student. He continued in this position till 1891, when he secured the Bachelor's Degree in Physical Sciences. Next year he was appointed at Lecturer in Physics at the same college.

It was during the period that Venkata Raman (later known as C. V. Raman), as wel! as his elder brother Subramanian (later known as C. S. Iyer), were born, As usual at the times of confinement the mother was staying in her father's. Saptarshi Sastriar's house at Thiruvanaikkaval. Later in life, when some one asked Professor Raman whether he was born with a "silver spoon", he replied that he was born with no spoon at all, and that his father's salary at the time of his birth was only ten rupees a month. Raman's ability to carry out great scientific investigations with simple inexpensive equipment, was perhaps a result of such financially modest beginnings.

Raman was born on November 7, 1888, Four years later, in July 1892, his father moved to Vizagapatnam, as a Second Assistant to the Principal of Mrs. A.V. Narasimha Row College. Besides

teaching physics, mathematics, and physical geography, Chandrasekhara Iyer took an active part in sports and physical culture. He was a great athlete himself.

At Vizagapatnam, the family was living close to the sea. Chandrasekhara Iyer took interest in music, mainly instrumental–Veena and Violin. He gave lessons in music to Raman's mother. During this period Chandrasekhara Iyer had an ardent desire to secure an M. A., first in Physics, then in Mathematics, and later in English Literature. He had collected books in all these subjects and did a lot of study. Due to various circumstances he did not appear for the respective university examinations.

Raman was thus exposed to a highly intellectual atmosphere at home since birth. His father was a teacher immersed in education. His residence on the sea beach provided scenes of great natural beauty—the red of the sunrise, the blue of the sea and the while spray of the breaking waves. Such an environment inside and outside home, would have significantly contributed towards Raman's "unusual appreciation of English literature and facility in idiomatic expression", and of course towards his intense love for physics, musical instruments, and the light and colour of natural phenomena.

III

Education

Raman was a precocious boy. In spite of his father being a great athlete, Raman was of a weak physical constitution in his early youth. As already mentioned his father took a bold step of detaching himself from his old environment and took up a job at Vizagapatnam, a Telugu speaking area, hundreds of miles away from his ancestral home in Tamil Nadu. Excelling in studies is perhaps the only means of providing satisfaction to a proud but physically weak boy placed in an unfamiliar environment where even the mother-tongue is different. And Raman did excel in his studies.

His father's library well stocked with books in English literature, physics, and mathematics was very conducive to the gifted boy's academic growth. He won prizes and scholarships in the school. He stood first class first in the matriculation examination when he was just eleven. Such a performance is impossible these days. Our present rules and regulations are rigid and have an ultimate effect of bringing brilliant and mediocre students to a common average level. Apparently Raman's interest in Physics was great even in those days. I am told that he had mastered that classic book—Ganot's Physics in his school days. It is said that while he was in the middle school he built all by himself an electric dynamo from a scratch. There is a story that on one occasion, when he was bed-ridden, he was so much enamoured of the working of a Leyden Jar*, that he would not go to sleep. His father had to bring the equipment from his college and demonstrate it by the bedside of Raman to save him from insomnia. This reminds one of how as a boy Einstein was fascinated by a magnet attracting

iron fillings from a distance, and how that fascination stayed with him throughout his life.

Raman continued his studies for the First Year Arts (F.A.) examiniation, at the Vizag College, where his father used to teach. In 1902, he passed his F. A. Examination held by the University of Madras, taking a first class and obtaining a high rank, and thereby winning a scholarship for higher studies.

In January 1903, he moved to Madras and joined the Presidency College for the Bachelor's degree with Physics as his main subject. His first entrance as a boy of fourteen into the English class created a mild sensation. The Professor addressing him asked: "Do you belong to this class?" Here is a paragraph from one of Raman's writings about his college days, in which the above incident is referred to.

> "Some of my pleasantest recollections of the four years I spent at college in Madras are of the extra-ordinary kindness and consideration which I received from the European members of the staff who were then the Heads of Departments of study. Their attitude seems all the more surprising when I look at the undistinguished and dimunitive figure of my self thirty five years ago as it appears in the college photographs of those days. Wearing a loin-cloth in the cylindrical style of boyhood and a home-knitted cap of wool which had no particular shape, I could readily have been mistaken for high school lad who had by accident got mixed up with a college crowd. Indeed in the first English class I attended, Professor E.H. Elliot addressing me asked if I really belonged to the Junior B. A. Class, and I had to answer him in the affirmative. He then proceeded to inquire how old I was".

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* This is an old gadget, which along with another gadget known as the Wimshurst Machine produces electric sparks.

In addition to his flair for science, Raman had an unusual appreciation of English literature. Another passage appearing in one of Raman's later writings about his college days at Madras, illustrates this aspect.

> "The English classes were conducted by Professors Bilderbeck and Elliot. They held their classes usually in the big lecture hall overlooking the sea, and the seats were so arranged that if the students did not like the lecture, they could instead gaze at the far horizon of the blue sea or count the glittering waves as they crashed down on the beach. Did ever students of the English language have a more marvellous panorama the contemplation of the beauty of which could lighten their labours? I am almost tempted to compare it with the glorious theatre built by the ancient Greeks on the height of Taormina from which you could see the waves of the Ionian Sea washing the coast of Sicily, or turning your eyes up, you could see the glittering heights of Mount Etna. It must be said to the credit of the teachers I have mentioned they often did hold our attention in spite of the lure of the swirling waters of the ocean breaking upon the shore, or was it because of the same fascinating vision of the sea that our minds were better attuned to the complicated beauties of the English language? I have vivid memories of the spirit with which Professor Bilderbeck conducted his classes and sought to infuse into us a due appreciation of the great English writers".

Apart from the gift of expression, this passage is an indication of Raman's fascination for the blue of the sea and its glittering waves. Almost twenty years later, he did fundamental scientific work on the 'colour of the sea', an intense follow up of which led him to the discovery of what is now called the 'Raman Effect'.

Raman passed his B.A. Degree examination in 1904, winning the first place and gold medals in English and physics. Some of the certificates that his teachers gave him speak volumes about his ability and strength of character. 'The best student I have had in thirty years'. 'A young man of independence and strength of character'. 'Exhibited an unusual appreciation of English literature and a facility in idiomatic expression'. 'Possessing great alertness of mind and a strong intellectual grasp.'

When he passed his B.A. examination his teachers suggested that he should go to England for further studies. But the civil surgeon of Madras ruled it out by disqualifying him medically, saying that he will not be able to withstand the rigours of the English climate. We have to be ever grateful to this man, for we know that an orthodox South Indian genius Ramanujam succumbed to the rigours of the English climate during the early nineteen twenties.

Raman, therefore, joined the M.A. course in physics at the Presidency College itself. In an article for the centenary of the college, he wrote: "Professor Jones believed in letting those who were capable of looking after themselves to do so, with the result that during the four years, I was at the Presidency College., I enjoyed a measure of academic freedom which seems almost incredible. To mention only one detail, during the whole of my two years' work for the M.A. Degree, I remember attending only one lecture, and that was on the Fabry-Perot by Professor Jones himself". It may be for the good of all concerned, if some provision is made in the present university rules for exempting the very bright students from attending routine lectures. There is a large amount of obsolescence in the prescribed curricula of our universities, the lectures often being almost a repetition of what the lecturers themselves had heard while they were students. And the bright students detect this obsolescence in no time with the consequent strained relationships between the teacher and the taught.

That freedom given to Raman did pay rich dividends. The college at that time was a teaching institution with no tradition what-so-ever for research. In those days research in modern science

was quite unknown in India. At the age of 16, while measuring the angle of a prism using a college spectrometer, Raman observed some diffraction bands when viewing the reflection near the grazing angle of incidence. He investigated these and found the correct explanation which was not available in the literature at that time. He wrote it up in the form of a research paper and gave it to Professor Jones. On receiving no comments from him, Raman took courage and sent it to the Philosophical Magazine (London) under the title: *Unsymmetrical Diffraction Bands due to a Rectangular Aperture*. The paper was published in November 1906. It is interesting to see that it contains no acknowledgment for any kind of help received from any one else. Obviously Raman could stand on his own and developed an unusual degree of self-confidence even in those days. This paper was followed by a note in the same journal on a new experimental method of measuring surface tension. During that period he also had correspondence with Lord Rayleigh, the great mathematical physicist, who mistook him to be a Professor at the Presidency College and addressed him accordingly.

Raman passed the M.A. Examination at age of 18 in January 1907, with a First Class, topping the list of successful candidates.

IV

Service in the Financial Department

(The Physicist in Hybernation)

On the advice of his teachers and other well-wishers Raman appeared for a competitive examination in February 1907, at Calcutta, held for selecting civil servants for the Finance Department. He again topped the list of successful candidates. That Raman, with all the flair he had shown for original scientific work, had to seek a job in the Finance Department clearly shows the singularly unsatisfactory environment for any scientific work which prevailed in India at that time. Conditions are different now and that they are so is in no small measure due to the efforts of Raman and his illustrious students. This was one of his roles as a nation builder.

While still awaiting his posting Raman found a bride for himself–Lokasundari (literal meaning the world's most beautiful maiden). The story has it that on the first occasion he met her, she was playing the Thyagaraja Keertana *Rama ni samana evaro* (Ram, is any one your equal) on the Veena, Apparently her proficiency in music and fine arts and individualistic charm made Raman decide to marry her. That she belonged to a sub-caste different from his own did not deter him. This alliance was against all conventions of the time. However, since the bride's age was only thirteen, the marriage took place with the consent of the father of the bride. Subsequent events proved that Raman made a very wise choice in taking Lokasundari Ammal as his life companion. She did not have a formal schooling, but was highly talented. Her proficiency in music, vocal and instrumental, her love of fine arts, and above all her steadfast devotion to Indian traditions of womanhood made

her an ideal and understanding wife. She often said that her principal interest in life was to help her husband in his intellectual pursuits. They had two sons Chandrasekhar and Radhakrishnan, born in the years 1921, and 1929 respectively. She was a loving mother to the numerous youngsters who came to Professor Raman as his students.

In June 1907 the young couple moved to Calcutta where he joined as the Assistant Accountant General.

They rented a house in Scots Lane, off Bow Bazaar Street. Within a few days of his reaching Calcutta, while on his way to work by tram, he saw a sign which read, "The Indian Association for the Cultivation of Science" the address was 210, Bow Bazaar Street. It was a privately endowed scientific institution founded in 1876 by Mahendralal Sarkar. At the time when Raman accidentally saw the sign board, Shri Amritlal Sarkar, son of the founder was the Association's Secretary.

Very soon Raman went to this Secretary and secured for himself facilities to work at the Association Building. There was a lecture hall and a large laboratory with a lot of unused equipments mostly of the demostration type. Dr. Mahendralal Sarkar had established the Institution with the desire that it would serve as a combination of the Royal Institution of London and the British Association of Science. Although Mahendralal advocated the cultivation of science by original research, all that happened was a number of popular lectures. At the time of his death, around 1904, he could only wish that younger men should come up and make his Institution really great. It happened in 1928, when Raman through his work at this Institution discovered the Raman Effect, for which he was awarded the Nobel Prize for Physics, in 1930.

After getting associated with this Institution, Raman got into an extremely busy routine;—5.30 a.m. arrives at 210, Bow Bazaar, returns home at 9.45 a.m. has a quick meal and goes to office; after 5 p.m. he goes to the laboratory straight, and comes home only around 10 p.m. Sundays were spent at the Association. Raman

continued to follow practically the same routine at Bangalore also, almost till the end of his life. He was a real *Karma Yogi*.

There was a short interruption of his scientific work at the Association. He was transferred to Rangoon in 1909 and then to Nagpur in 1910. Although he had no laboratory to work during this period, he kept up his scientific interest and rigged up all kinds of gadgets at home for working outside office hours. Fortunately this period of exile was short; he was transferred back to Calcutta on promotion in 1911. He was delighted to re-enter the Association Laboratory.

His only colleague-cum-assistant in the Laboratory was Ashutosh Dey—the faithful Ashu Babu, who had never entered the portals of a university. During this period about thirty scientific papers of high quality were published. Most of them came out in the *Bulletin of the Indian Association,* the others in international journals like the Philosophical Magazine, Proceedings of the Royal Society, and the Physical Review. In many papers Ashu Babu was the co-author. Raman was particularly proud of a paper published in the Proceedings of the Royal Society. London, in which Ashu Babu was the sole author.

Thus, in spite of arduous duties of his office, Raman sought and found opportunities to carry out theoretical and experimental scientific investigations, sometimes under difficult and improvised conditions. His investigations were in the field of acoustics and optics. All kinds of wave-motion fascinated him. There are papers on the bowed string, the struck string, the maintenance of vibrations, resonance, the sounds of splashes, singing flammes, music from heated metals, the veena, the violin and the Indian drums–the *mridangam* and the *tabla.* He found that the bridge of the Veena is so cunningly constructed that the instrument can produce innumerable musical over-tones and thus closely resemble the human voice which can generate overtones upto the sixteenth harmonic. It was proved through his investigations that the non-homogenous loading of the membrances in the Indian musical drums, was a clever device for generating overtones, which made

them behave almost like stringed instruments. He also published during this period about five papers dealing with the diffraction of light.

In spite of all this heavy work outside office hours, the quality of Raman's official work was very high. While he was an Officer at Nagpur, a citizen brought him a bundle of hundred rupee currency notes which was nearly burnt in a fire accident, with a request that they may be replaced by fresh ones. The scientist in Raman made him scrutinise the charred bits of the currency notes and discover the numbers and other markings. He recorded that he was satisfied that it was a genuine case, and instructed the treasury to issue fresh notes to the grateful applicant.

When the Vice-Chancellor of the Calcutta University wrote to Government of India for permitting Mr. Raman to go to the University for a period of two years as an 'Experimental' Professor, the then Member (Finance) of the Viceroy's Council did not agree, but wrote : "I find that (Mr. Venkata Raman) is most useful in the Finance Department, being in fact one of our best men". However, when Sir Asuthosh Mukherjee, the Vice-Chancellor offered the post of the newly created Tarakanath Palit Chair of Physics, Raman accepted it, in spite of a reduction in emoluments it involved.

While announcing his plans for filling the Chair, Sir Ashutosh Mukherjee stated: "For the chair of Physics created by Sir Tarakanath Palit, we have been fortunate enough to secure the services of Mr. Chandrasekhara Venkata Raman, who has greatly distinguished himself and acquired European fame by his brilliant researches in the domain of physical science, assiduously carried out under the most adverse circumstances, amidst the distraction of pressing official duties....

"I shall fail in my duties, if I were to restrain myself in my expression of the genuine admiration I feel for the courage and spirit of self-sacrifice with which Mr. Raman has decided to exchange a lucrative official appointment for a University Professorship, which I regret to say, does not carry even liberal emoluments. This one instance encourages me to entertain the hope

that there will be no lack of seekers after truth in the Temple of Knowledge which is our ambition to erect”.

On the same issue, Raman remarked later that Sir Ashutosh’s offer of the Professorship to an unknown government official was an act of great courage, while his acceptance thereof was only a case of following his inclination.

Raman joined the Calcutta University as Palit Professor of Physics and thus ended his hybernation period during which he was a Civil Servant. He brought great honours to that Temple of Knowledge, but alas ! Sir Ashutosh Mukherjee did not live to see his protege bring the Nobel Prize to the Temple erected by him.

V

Palit Professor C.V. Raman

(The Golden Era 1917-1932)

Professor C.V. Raman left service under the Government of India and became the first Tarakanath Palit Professor of Physics, in July 1917. As mentioned earlier he was closely associated with the Indian Association for the Cultivation of Science since 1907. In 1919, Shri Amritlal Sircar passed away and Professor Raman was elected Honorary Secretary of the Association. Thus Professor Raman got full control of the two laboratories to conduct research work–the laboratory at the University, and the laboratory at 210, Bow Bazaar Street.

Apart from investigational work he had to teach at the University as well and was rated a highly successful teacher. His lectures were very lucid and did not deal with mere text-book material. These lectures invariably attracted a large number of students. He rented a building, adjacent to the Association building. To further facilitate his work. Professor Raman arranged to have part of the separating wall broken and to have a private door connecting his residence to the laboratory. By this arrangement he got access to the laboratory any time of the day and night.

Many young students gathered round him as research scholars. Initially they came from the Calcutta University, but later, as his name spread, from the distant parts of India as well. In those days research fellowships were not generally available, and if available the amounts were very small. So many of these scholars lived without much physical comfort. They had their beddings and other possessions kept in some corner of the Laboratory, and ate outside

in some inexpensive restaurant. At nights, between the experiments they were conducting, they snatched a few hours of sleep. Their whole interest was in scientific work under the inspiring guidance of Professor Raman–a true Acharya. *Acharatiti Acharya*: one who practices what he preaches—high thinking and plain living.

The laboratory at the Association Building was a scene of intense activity. There were no fixed hours of work. Several students had to work on the same equipment by turns. The Acharya used to come to the laboratory very early and would remain there till late at night, snatching sometimes here and there for his lunch or snacks. Visits to the laboratory after dinner were frequent. It was an entire 'family' engaged in high class scientific work—with practically no interests outside scientific research. A kind of *tapasya,* similar to that of our ancient *rishis* who evolved our Vedanta.

Professor Raman steadily increased the resources of the laboratory through his personal efforts. He got small amounts of money from various resources. Such meagre resources supplemented by a galaxy of gifted collaborators from all over the country enabled Raman to go ahead and make the laboratory of the Indian Association for the Cultivation of Science the best place for scientific work in India and perhaps anywhere else in the world during that period. The Association published an impressive series of outstanding scientific papers in various journals. Some of the areas in which substantial progress was made were: theory of musical instruments, wave optics such as diffraction, interference, colours and polarisation, colloids, x-rays, magnetism, magneto-optics, electro-optics, viscosity and above all molecular scattering of light. These were published in standard international journals and as Bulletins of the Indian Association for the Cultivation of Science. The world scientific community gradually became aware of the great work done at Calcutta by the Raman School. Professor Raman also gave lucid popular lectures which attracted large elite auidence. Thereby, he acted as the most successful "Salesman for Science" in India.

One of the conditions laid down by the donor for the appointment to the Palit Chair was that the appointee should have been trained abroad. As Professor Raman refused to go to England for "*training*", Sir Ashutosh, the great administrator, amended the provisions of the endowment. However, in 1921, he prevailed upon Professor Raman to go to England as a *delegate* to the Universities' Congress held that year in Oxford. By this time he had already published several papers in acoustics and optics and his work was known and appreciated in the scientific circles of England and Europe. During this visit he met the famous English physicists: J.J. Thomson, Rutherford and W.H. Bragg.

At London he visited the St. Pauls Cathedral and was fascinated by its Whispering Gallery. He carried out a few experiments in collaboration with Sutherland and before his return published the findings in the form of two papers one in *Nature* and the other in the *Proceedings of the Royal Society*.

It was during this voyage that Professor Raman saw for himself the deep blue colour of the Mediterranean Sea, It would have rekindled his early wonder at the blue of the Bay of Bengal observable from the beaches at Vizagapatnam and Madras. In the scientific literature Lord Rayleigh had successfully explained the blue colour of the sky as due to the scattering of sunlight by the molecules of oxygen and nitrogen present in the atmosphere. He had explained away the blue colour of the sea with a simple statement: "the much admired dark blue of the deep sea ... is simply the blue of the sky seen by reflection". Raman felt that this explanation was unsatisfactory. On his return voyage he carried with him a polariser–a Nicol Prism. The reflected light from the sea, at a particular angle of reflection would be completely plane polarised and, therefore, would be capable of being quenched by a suitably oriented Nicol Prism. Professor Raman found to his personal satisfaction, that this quenching *did not* take place. Instead the sea was still glowing with a vivid blue. Obviously the light was coming from inside the water. At this stage, I quote Professor Raman:

> "A voyage to Europe in the summer of 1921 gave me the first opportunity of observing the wonderful blue opalescence of the Mediterranean Sea. It seemed not unlikely that the phenomenon owed its origin to the scattering of sunlight by the molecules of the water. To test this explanation, it appeared desirable to ascertain the laws governing the diffusion of light in liquids and experiments with this object was started immediately on my return to Calcutta in September 1921. It soon became evident, however, that the subject possessed a significance extending far beyond the special purpose for which the work was undertaken, and that it offered unlimited scope for research. It seemed indeed that the study of light scattering might carry one into the deepest problems of physics and chemistry, and it was this belief which led to the subject becoming the main theme of our activities at Calcutta from that time onwards".

To be specific, immediately on his return to Calcutta, Professor Raman started three lines of investigations:

1. The scattering of light by liquids
2. The scattering of x-rays by liquids
3. The viscosity of liquids

In December 1921, K. R. Ramanathan, the most gifted of Raman's collaborators, joined him as a Research Scholar of the Madras University. For his outstanding scientific contributions during the course of a single year, the Madras University conferred on Ramanathan the D.Sc. degree. He was the first person to receive this degree from the University of Madras, and perhaps the only one to secure it in the record time of one year.

Dr. Ramanathan was involved in both the fields of study; scattering of light by liquids and scattering of x-rays by liquids. They did not pursue x-ray scattering beyound contributing a classical paper on x-ray scattering by liquids published in 1923.

Professor Raman did substantial work in viscosity also, but again left it off. Professor Raman's mental powers were almost exclusively devoted to the problem of light scattering by liquids, solids and gases.

In 1922, Raman wrote a comprehensive essay on the Molecular Scattering of Light which was published by the Calcutta University Press. Dr. Ramanathan gave substantial help in the preparation of this essay. The essay indicated several problems requiring solution. These were investigated with the aid of a succession of able collaborators: K. R. Ramanathan, K. Seshagiri Rao, K. S. Krishnan, S. Venkateswaran, A. S. Ganesan, L. A. Ramdas, C. M. Sogani, N. K. Sur, N. K. Sethi, S. K. Datta, P. N. Ghosh, B. Banerji, I. Ramakrishna Rao, B.B. Roy, B.N. Sreenivasiah, S. Bhagavantam, and so on. The non-isotropic nature of molecules in their optical behaviour was the objective even when he investigated the diffraction of x-rays by liquids. The studies enabled a connection to be established between the molecular non-isotrophy in fluids and the optical, electrical and magnetic anisotropy exhibited by solids in the crystalline state.

Raman's works on acoustics was carried out before he fully launched on the molecular scattering of light, but had earned for him a global fame in acoustics. As a sequel, Prof. Raman was invited to contribute a lengthy article on the Physics of Musical Instruments to the Handbuch der Physics published in 1927 by Julius Springer, Berlin. Having accepted the task, Raman found that it was consuming a lot of his normal working time. I was told, that he finally accomplished it by working on it between 4 a.m. and 6. a.m. in the morning every day almost for four months. Sardar K.M. Panikkar has recorded that while he was busy all day with his official duties as the Dewan of the Patiala State, he wrote his books utilising these early morning hours usually spent in sleep by others.

A few of the details of Raman's scientific work which culminated in the discovery of Raman Effect in 1928 are described in the next Chapter.

Raman undertook a second trip abroad in 1924, when he was invited to join the British Association for the Advancement of Science in a tour across Canada. He was a guest speaker at a Scientists' Convention in Canada and was requested to open a discussion on the scattering of light at Toronto. During that visit, Raman extensively toured Canada, USA, England, and Norway. At the invitation of Professor Millikan, he stayed on for four months as a Visiting Professor, at the California Institute of Technology. He attended the centenary of the Franklin Institute of Pennsylvania as the representative of India in 1925. During the same year he again visited Europe as a guest of the Russian Academy of Science to represent India at the bi-centenary celebrations of the Academy in Leningrad and Moscow. In 1929, Raman was invited by the Faraday Society to open a discussion on Molecular Spectra. During that visit he visited and lectured at several places in Europe. Subsequently he again visited Europe to receive the Hughes Medal of the Royal Society, London, and the Nobel Prize at Stockholm, both in December 1930. He went to Paris in 1932, to receive Honorary Dectorate. Professor Raman told me once that in most of these countries, there were occasions which reminded him that he was not a whiteman; France and the Soviet Union were the only countries where he was not made to feel so.

The Royal Society of London elected him to its Fellowship in 1924. The British Government in India conferred a Knighthood on him in 1929. In 1928, be was awarded the Matteucci Medal by the "Societa Italiana Della Scienza" of Rome.

In April 1933, Raman received an invitation from Bangalore to become the first Indian Director of the Indian Institute of Science there. While he accepted the invitation, he had apparently some doubts about the wisdom of such a move, for he wrote to the Culcutta University– "....I am far from being sanguine that the transfer from a University Professorship to an Administrative position is really an advantageous step in the career of a man of science". He finally accepted the offer and moved to Bangalore.

Regarding Raman's move to Bangalore, Fermor (the then Director General of Geological Survey) said: "At present Calcutta may be regarded as the Centre of Scientific Research in India. But with the transfer to Bangalore of one of her leading investigators, Calcutta will have to guard the laurels".

VI

Raman Effect and Nobel Prize

Professor Raman has often stated that ambition, courage and endeavour have been his watch words. He was elected a Fellow of the Royal Society of London in 1924. The University of Calcutta threw a dinner to felicitate him on that recognition. Sir Ashutosh was present. It seems that he asked Professor Raman quite jocularly, “What Next”? and that the reply was equally brief but serious, “The Nobel Prize”. Many would say that it was an evidence of his boastful nature. But it should be interpreted as his ambition and a realistic estimate of his own powers expressed very briefly. An ambition can never be achieved unless it is backed by courage and endeavour; and Professor Raman had plenty of both.

As mentioned earlier, he had taken up a residence adjacent to the premises of the Association at 210, Bow Bazaar Street, Calcutta. Later he had a door installed in the wall, so that he could enter and leave the laboratory at any time of the day or night quite informally.

We have mentioned earlier, how Professor Raman’s voyage across the Mediterranean Sea in the summer of 1921 had set his mind on the molecular scattering of light by liquids. Within a few weeks of his return he (and Seshagiri Rao) had measured the intensity of the molecular scattering of light from water. They established that the Einstein-Smoluchowski concept of random clustering of molecules could be extended to explain molecular scattering almost quantitatively.

Even before the discovery of the Compton Effect in 1923 Raman had thought of the interaction of light quanta with the molecules of matter, in which energy transfers could take place

between the light quanta and the molecules. In April 1923, at Raman's suggestion Professor K.R. Ramanathan, the oldest and among the most distinguished of Raman's students, made a detailed study of the scattering of light in water. Sunlight was focussed on the liquid and the scattered light when viewed in a direction transverse to that of the incident beam was seen as a track inside the liquid. A system of complimentary filters was devised, each filter, completely cutting off the light transmitted by the other. When the incident light was passed through one filter and then allowed to fall on the liquid, and the scattered light viewed through the other filter, no track should have been visible, if there had been no change of colour in the process of scattering. But Ramanathan observed a track. This was attributed to a "weak fluorescence" due to impurities which were believed to be present.

However, in spite of repeated "purifications" and the use of different kinds of purified liquids, the phenomenon of "weak fluorescence" persisted. It obviously involved a change of colour. These experiments continued to be performed by different workers in that laboratory for the next five years; they used different scattering media: solid, liquid as well as vapour. All the time Professor Raman was not satisfied with the explanation. On a few occasions when he found the bright track in benzene in the experimental arrangement set up by K.S. Krishnan, he used to exclaim; "is all this fluorescence". It was late in February 1928, when studying the light scattered by pure benzene that it flashed into Professor Raman's brain to use a mercury arc and to view the "fluorescent track" through a direct vision spectroscope. A Zeiss Cobalt-glass filter placed in the path of the incident beam from a mercury are cut off all visible light of wavelenghts longer than that of the bright violent indigo region present in the beam incident on a flask containing pure benzene. In the spectrum of the light scattered by benzene a bright band in the blue-green region was observed by Raman, separated by a dark interval from the indigo-violet region transmitted by the filter. *Both* of these regions in the spectrum of the scattered light became sharper when the region of transmission was narrowed by the insertion of an additional filter

in the incident beam. The experiment was repeated with a variety of liquids and solids, *and the startling observation was made that the spectrum of the scattered light generally included a number of sharp lines or bandson a diffuse background which were not present in the light of the mercury arc. It was a new radiation.* All this happened on February 28, 1928. The announcement of the discovery of the "New Radiation" in the light scattered by molecules, was made to the Associated Press on February 29, 1928, The announcement was made because Prof. Raman was very confident of the importance of this discovery. This is the Raman Effect.

The quartz mercury lamp was so powerful and convenient a source of monochromatic illumination that in the case of liquids and solids photographing the spectrum of scattered light was found to be easy. The earliest pictures of the phenomenon were taken with a Hilger Baby Quartz Spectrograph.

The work of Compton in x-ray scattering (for which the 1927 Nobel Prize was awarded) had gained general acceptance for the idea that the scattering of radiation was a unitary process, in which energy was conserved. Any gain of energy by the scattering particle during the encounter with the quantum, would mean that the quantum would be deprived of energy to the same extent, and accordingly, would appear after scattering as a radiation of diminished frequency of longer wavelength. The agreement of the observed displacements with the infra-red frequencies of the molecules made it clear that the Raman Effect opened up an illimitable field of experimental research in the study of the structure of matter.

Before long many laboratories in the world took up the study of the Raman Effect in simple molecules. But in Raman's laboratory the emphasis was on the study of more fundamental problems connected with the physics of the liquid and solid state using Raman Effect as a *Tool*.

Professor Raman was knighted by the British Government in India in 1929. The entire equipment used for the discovery cost

less than two hundred rupees–a mercury lamp, a flask of benzene, and a direct vision spectroscope. Several years later, reminiscing about the discovery Professor Raman remarked, "The essence of science is independent thinking, hard work and not expensive equipment". Conditions have apparently changed, now-a-days expensive equipment is also perhaps necessary.

Raman was awarded the Nobel Prize in Physics "for his work on the Scattering of Light and for the discovery of the effect named after him", for the year 1930.

Nobel Prizes are announced in the second or third week of November. The meetings of the Nobel Committee are held in the highest secrecy and the awards are announced in November about a month before the prize giving ceremony at Stockholm around mid-December. Professor Sir C.V. Raman had anticipated the possibility and booked his sea passage in July itself, so that he could be there at Stockholm in time to receive the award.

The award was made on December 10, 1930, and Professor Raman delivered the obligatory Nobel Lecture on the next day. Lady Raman had accompained him on this tour also. As was the custom, all the Nobel Laureates were treated to a grand dinner that evening, the hosts being the King and Queen of Sweden. During the dinner, one of the invitees said: "This morning Raman demonstrated his effect on alcohol. Now we would like to see the effect of alcohol on Raman". So saying he pushed a glass of an alcoholic drink towards Raman. True to classical traditions, with polite thanks, Raman returned the glass and sipped water instead. He was a teetotaller with conviction and courage.

Professor Raman's Nobel Lecture illustrates his unique ability to expound intricate scientific discoveries to large audiences. Therefore, this lecture is reproduced in full as an Appendix to this biography.

After a spurt of activity on Raman Effect all over the world for about fifteen years, a lull set in. Most of the solid, liquid, and gaseous substances had been investigated. However, with the

advent of the Laser–Light Amplification by Stimulated Emission of Radiation–in 1960, and the first use of a Ruby Laser to obtain a Raman Spectrum in 1962. Raman Spectroscopy revived and attained greater and greater heights. One of the early experimenters, Professor Bhagavantam "slept under the spectrograph with protecting glasses for two nights with the exposure on" before he could get a reasonably good photograph of the Raman lines scattered by a 140 carat diamond. With a laser as a source this can be done in a couple of seconds or less and with a much smaller diamond. With powerful and even tunable laser sources Raman spectorscopy has found new applications in industrial chemistry, in pharmaceutics and in biology. It can also be used for the remote sensing of the atmospheric constituents upto altitudes of 50 kilometres or so with the optical transmitters and detectors located on the earth's surface itself.

The field of Raman Spectroscopy is thus in a developing phase even after more than fifty years after its original discovery. Due to several reasons, most of these developments are taking place outside India. It is hoped that before long young scientists in India also will participate in these activities.

VII

Director and Professor, Indian Institute of Science, Bangalore

Professor Raman joined as Director of the Indian Institute of Science, (IISC), Bangalore in July 1933. IISc is one of the most prestigious scientific institutions of India originally started in 1909 by the great visionary and industrialist J. N. Tata. Even now at Bangalore, this is known as the Tata Institute, Soon after taking charge, Professor Raman created a Department of Physics under him. Till then the Institute had only Departments of Chemistry, of Bio-chemistry, and of Electrical Engineering. The Director of the Institute had only administrative and co-ordinating responsibilities. The new Department of Physics enabled Professor Raman to collect students of Physics and to continue his own researches in Physics. Of course, this meant a certain amount of diversion of funds normally utilised by the other existing departments. It also meant that some of the bright students who otherwise might have joined the Electrical Department joined instead the Physics Department. All these led to some initial strain between the Director and the Heads of the other Departments.

When Raman joined the Institute he was at the pinnacle of his scientific fame. He was Sir C. V. Raman, Kt. F.R.S., Nobel Laureate. He made many changes in the administrative set up, the most important one being the direct involvement of the Director in active scientific research. He kept long hours at the office and the Department, his was only a continuation of his old practice, but at variance with the traditions at the Institute. He used to come to the Laboratory around 7 a.m. had a quick breakfast around 9 a.m. and was at the Director's seat at 10 a.m. Many of the

bureaucratic methods were cut for expediting the administrative work; it left enough time for him to attend to his personal research and guidance of his new students. He did not encourage his old students at Calcutta to come over to Bangalore and continue their research work under his guidance. He preferred fresh blood, and this meant more work for him. A new Physics Laboratory had to be set up, and this he did by reshuffling the existing accommodation in the main building, and without undertaking the construction of new buildings.

Often he continued to stay in the Laboratory till about 9 p.m. either carrying out his own personal research, or supervising and guiding the work of his students. For the typing assistance he needed in this connection, he employed a typist from his own personal funds, as the person had to keep odd hours. He thus set a difficult example to the research students and staff of other Departments, who had treated the Institute as a place of comfortable research and not competitive research. (Many of the Research Institutes in India which were places of *competitive research* when they commenced functioning soon after India's Independence have glided back to places of *comfortable research*. (Some of our research scientists consider research work comparable to other jobs in scientific service departments like the Telegraph Department.)

In 1933, many famous scientists were leaving Germany to escape from the tyranny of Hitler. Professor Raman felt that he could get a few of the Physicists among them to Bangalore and thereby produce a significant impact on Indian Science. Although he was successful in getting Prof. Max Born–a Teacher of a few Nobel Laureates, and later a Nobel Laureate himself–the mission on the whole failed. Co-operation from his colleagues within the Institute and from senior Indian Scientists outside Bangalore was lacking. There was even opposition; they were afraid of suffering by comparison with these German Scientists. The full benefit of the 1933 situation was reaped not by India but by the United States of America, who welcomed those top intellectual scientists with open arms.

At Bangalore, in spite of his multifarious administrative and social duties, Professor Raman made significant contributions in the areas such as ultra-sonics, X-ray diffraction, viscosity of liquids at high frequencies, magnetism and magneto-crystalline action, magneto optics, crystal growth, crystal dynamics, etc. He also had a deep interest in the colours of birds, beetles and butterflies. An experimental study of these along with those exhibited by sea-shells and various minerals under ultraviolet illumination provided problems for young scientists. That the investigation did not require expensive equipment was an added attraction.

Of these, his contribution in the field of ultrasonics jointly with Nagendra Nath has been outstanding. The theory of the diffraction of light by ultrasonic waves was based on a simple and elegant concept. A plane wave of light when it passes through an ultrasonic wave field is speeded up in regions of rarefaction and slowed down in regions of compression to emerge as a corrugated wavefront. This corrugated wavefront gets resolved as a number of plane wave fronts of different amplitudes and inclined differently to the original plane wave front. This idea cleared the air of many of the theories that were extant at that time.

Raman's interest in this subject led to a large amount of experimental work carried out by a number of his collaborators, particularly Prof. Bhagavantam and his students. This resulted in valuable contributions in this branch of high frequency acoustics emanating particularly from the Physics Departments of the Andhra and Osmania Universities.

Professor Raman had a great fascination for gem-stones. Opals, moon stones, feldspars, agates, rubies and diamonds were the objects of investigation in his Laboratory. The study of the diamond, its structure and its physical properties has been a life-long involvement for him. His interest in diamond was there even during his Calcutta days. The Raman Effect on diamond was first studied with a small brilliant in the marriage ring of his brother C. Ramaswamy*, who joined his research Laboratory in 1928. As

* Dr. C. Ramaswamy, retired as the Director General of observatories.

mentioned earlier, the next experiment on diamond was done with a 140 carat piece, loaned by the Maharaja of Darbhanga for a period of 2 days. Almost every student working in his laboratory had studied some property of the diamond at one time or the other. The Young's modulus, fluorescence, absorption, luminescence, birefringence, X-rays studies, specific heat, magnetic susceptibility, photo-conductivity, ultra-violet transparency, the Faraday-effect and a host of other properties were the subject matter of studies by him and his collaborators over a couple of decades. His library was well stocked with books on diamonds including the stories of some of the world-famous diamonds, which were originally obtained from diamond quarries in India. Apart from the "diamond pipes" at Panna, Raman had a feeling that there must be some "diamond pipes" somewhere in the valley of the River Krishna, in Andhra Pradesh, Vajra Karur for example.

He found that when a beam of x-rays traverses a diamond plate the octchedral planes of the crystal exhibit well defined reflections of monochromatic x-radiations. These reflections appear in positions clearly removed from the ordinary Laue reflections. He concluded that in this phenomenon we are encountering a second kind of x-ray reflection of a dynamic origin. The thermal energy in a crystal is in the form of thermal waves and they produced a dynamic periodicity in the crystal structure superposed over the more commonly known static periodicity of the crystal lattice. Diamond exhibits such reflections very conspicuously. In other crystals also the phenomenon exists but less conspicuously.

In 1934, Raman founded the Indian Academy of Sciences. Raman was the Founder President of the Academy and continued to be to till his death. He used to say that Sir Issac Newton, once he became the President of the Royal Society, continued to be so for his life time. One of the principal objectives of founding the Academy was to have a Scientific Journal in which he and his students could publish their scientific papers, without depending on a foreign journal to do so. While a foreign journal may give a wider publicity, to an active scientist saying the 'first word on a subject', the inevitable delay is often unacceptable. Prof. Raman

also felt that depending on a foreign journal for one's scientific publications was a sign of some kind of a national inferiority. He was aware of the limited circulation that an Indian journal might have among the foreign scientists. To overcome this, he would get three hundred reprints of the paper and distribute to the scientists who are likely to be interested in that subject but located in the different laboratories of the world, He said that it was cheaper, more effective and good for the image of India. That was true nationalism. He, when became mature, was not interested in getting approbation from foreigners. He wanted other senior scientists also to feel like him. He, therefore, refrained from recommending senior Indian scientists for Fellowships of prestigious Foreign Societies. And to make his point clear he resigned from his Fellowship of the Royal Society. (A story is told that an old lady whose son was eating a lot of brown sugar approached Shri Shankara to advise the boy to refrain from eating sugar. It seems that Shri Shankara advised the boy to do so, only after days; he said that he was eating brown sugar himself, and therefore, could advise the boy only after he had given up eating sugar.)

In his capacity as President of the Indian Academy of Sciences, he personally looked after the proceedings of the Academy. They were published with unfailing regularity throughout his Presidentship. All his papers were published there, so also those of his students. He acted as a referee to many papers to expedite their publications. It meant hard work. During the last three days of every month, most of his time he spent with the press, even reading the galley proofs when necessary.

The annual meetings of the Academy were deliberately held in University towns. He wanted the young University students to be exposed to what was currently happening at the Research Centres. He wanted those students to meet the scientists involved in flesh and blood. The most distinguished scientists of the country were invited (or ordered by Prof. Raman) to be present and to actively participate in the proceedings. It was a coterie of scientists talking only science. Raman always gave the Presidential address. There were also popular evening lectures, one of which was

delivered by Prof Raman himself. The others were delivered by men whom he selected on subjects he specified. It was a training ground for those eminent scientists. Among the Fellows of the Academy it was called "Raman Circus".

One of the serious routines in which Prof. Raman invariably indulged as President of the Academy was to call out loudly the names and occupations of the Fellows of the Academy and asking each of them to stand up and face the audience as their names were called out. To hear Prof. Raman expounding physics to general audience interspersed with humour was indeed an exhilirating educational experience. Raman showed himself to be an orator enthusiastic in sharing the beauty of science with his audience young and old, the elite and the common. Every man and woman, every boy and girl went back excited, feeling that they could also realise the beauty and philosophy of science. Raman's success as a scientific exponent was due to his being deeply involved in the subject emotionally as he was speaking. Several young people of the last generation have told this biographer, that they took to science because of having listened to one of these public lectures of Prof. Raman, just once.

In factories, it is well known that a very efficient worker becomes a marked man. His efficiency demonstrates the lack of it in others. This is a problem of human dynamics. Eventually Professor Raman also became a marked man. Perhaps there were also political overtones unfavourable to Raman functioning as the Director.

In 1937, Professor Raman relinquished the responsibilities of the Director. Not minding a decrease in his emoluments or bureaucratic status, he continued to be Professor and the Head of the Department of Physics. The scientist in him made him accept such a change with grace. In a letter to Prof. Raman dated August 3, 1937 Lord Rutherford wrote: "I am pleased to hear that you will be able to continue your work in Physics in Bangalore without all the worries and distractions involved in acting as Director of the Institute. Now that the matter is settled, I trust that you will be

able to carry on with your personal work and let bygones be bygones".

About this time Prof. Raman had an offer to be the Director of the Kammerlingh Onnes Laboratory at Amsterdam. Professor Raman politely declined the offer saying that his place of work was India. That was true patriotism, an intense desire to make India great.

He vacated the Director's bungalow and worked as the Professor of Physics for the next eleven years.

In November 1948, on attaining the age of superannuation, he retired from the Indian Institute of Science and was made a National Professor. By that time, he had built an independent Research Institute, mostly with his own funds and only nominally supplemented by a few donations.

VIII

Raman Research Institute

Retirement from the Indian Institute of Science at the age of 60 had to be an inevitable event, obvious to Prof. Raman. For him the pursuit of science had always been an aesthetic and joyous experience. After retirement from the Indian Institute of Science, he wanted a place in which he could continue his studies in an atmosphere more conducive to pure research than that found in most scientific institutions.

Therefore a few years before 1948, he collected some private donations, added his own savings to that and commenced the construction of a building on a large piece of land gifted to the Indian Academy of Sciences by the Government of Mysore. The building was completed in the year 1948, in time for him to move straight into it from the Indian Institute of Science. Even in those days the question of 'relevance to the economy of the country' in any kind of financial commitments by the Government was cropping up in the minds of administrators and politicians. Therefore, Raman was anxious to keep his Institute independent of Government grants. It appears that there was a feeler sent out to see how he would like to be the Vice President of India. He is reported to have laughed at the suggestion and to have remarked "What shall I do with that ship (Vice Presidentship)?" It shows his unswerving dedication to science.

Lack of substantial grants was a handicap. But Raman was undeterred. He selected a few able young scientists and made his Institution a great centre of research. Many outstanding publications again began to flow under his guidance and inspiration. They were on topics like the generalised theory of interference,

the theory of optical activity in crystals, etc., investigations not requiring expensive equipment.

He was greatly disappointed when he found that large amounts of money were made available for scientific work in imitation of and as a follow up of scientific work carried out in Western countries. This was necessarily carried out with expensive imported equipment. The method of "big science" was not in tune with his ideas, which emphasised individual eminence. He did not fully realise that after World War-II "big science" exemplified by atomic power, rocket explorations and the like had come to stay. It was felt by Indian and foreign administrators and their advisor scientists that the economic betterment of India lay in the application of big science in a big way. The consequent clash of ideas between Prof. Raman and those in power in India, made him shy away from the scientific activities of the big National Laboratories of India. For him science was what others called "Ivory Tower Science"–a passionate attempt to understand Nature, untramelled by thoughts of relevance and practical utility.

His feeling of frustration at the sight of Indian scientists running after the ways of Western science, was further heightened by several young scientists including some of his own getting out of the country for work at the various scientific institutions in USA, Canada, etc. After the World War-II, those countries spent large sums of money towards development of science and technology and Indian talent was more than welcome. To the young Indian scientists it meant good opportunity for work, and also good money compared to Indian standards.

Prof. Raman became a recluse and devoted all his time to personal research unaided by Research scholars. He launched upon his researches on the colour of flowers in his garden and the physiology of human vision. The equipment was his own eyes, a direct vision spectroscope and the coloured flowers of his garden. He published several articles on the subject. One of his principal findings is that the existence of any light in the yellow region of the visible spectrum tends to suppress the sensation of all kinds of

colour. The eye sees any colour as a bright rich colour only if the intensity in the wavelengths corresponding to the narrow yellow region of the spectrum is low or altogether absent. He also showed that the sensation of colour is highly dependent on the total intensity of light; in poor light there is no sensation of colour. His investigations on the human appreciation of colours were subsequently consolidated into a book: *The Physiology of Vision.* Since no commercial publisher has pushed the sales of this book, it is less known even among the scientists.

After a few years Prof. Raman came out of depression and began to enjoy the company of school boys and girls. He became once again the wide-eyed child of Nature, inquisitive about all aspects and phenomena observable in the open. For him God was in this world, in the observable and analysable Nature. In a sense his concept of God was somewhat similar to that of Einstein—a Supreme Power responsible for the observable harmony in Nature. On the occasion of laying the foundation stone of the Vikram Ambalal Community Science Centre, in December 1968, Prof. Raman (at the age of 80) delivered an inspiring, thought-provoking lecture, addressed to school children. The title of the lecture was : *Why the Sky is Blue?* It contained much guidance on how to think on a subject scientifically. It is felt that every school boy and girl should carefully read this lecture; even teachers can benefit. Hence this lecture is reproduced in full as Appendix–V.

In September 1970, Raman arranged the annual session of the Indian Academy of Sciences at Bangalore. Usually this is done in the month of December. Probably Raman had a premonition. The session lasted one full week. Young scientists were invited to present reviews of progress in different subjects: Nuclear Science, Radio Astronomy, Meteorology, seismology, Crystallogrphy, Genetics, Agricultural Science, and Neuropsychology. In spite of failing health, he attended all of them and, as usual, took an active part in the discussions that followed. On October 2, 1970, he delivered the Gandhi Memorial Lecture–that was the last lecture he delivered in his life. In it he gave, as usual, a masterly exposition of his ideas on the theory of hearing.

Professor Raman had an early break-down in early November but recovered. He passed away peacefully on the morning of Saturday, November 21, 1970, 82 years and 14 days after he came into this world. His bodily remains were cremated on the grounds of the Raman Research Institute, Bangalore.

He was blessed with an ideal wife, Lady Lokasundari Ammal, who lived only to serve the genius Raman. On his passing away she said “I came into this world only to serve him, and now my duty is finished.” Raman was survived by his wife and his two sons, Chandrasekharan and Radhakrishnan. The latter is now the Director of the Raman Research Institute.

Bharata Ratna Chandrasekhara Venkata Raman walked like a colossus over the Indian scientific theatre for more than half-a-century. He was great through the richness of his scientific discoveries, as well as through his outstanding ability in training a large number of Indian scientists. He inculcated in them self-confidence, self-reliance, self-respect and courage and through them showed that India has great potential of becoming a great nation. Thus he had a big hand in building India in the scientific field. The Indian nation and the world scientific community as a whole are ever grateful to him for what he has given.

Honours Bestowed on Raman

1924	Elected Fellow of the Royal Society, London
1928	Matteucci Medal–Societa Instaliana Della Scienza, Rome.
1929	Knighted by the British Government in India.
1930	Hughes Medal–Royal Society, London
1930	Nobel Prize—Stockholm, Sweden
1935	Rajasabhbhushana–Decoration by the Maharaja of Mysore.
1941	Franklin Medal, USA
1954	Bharata Ratna–Decoration by the President of India.
1957	Lenin Prize, USSR

Honorary Doctorates from the Universities of :

Allahabad, Benaras, Bombay, Calcutta, Dacca, Delhi, Freiburg, Glasgow, Kanpur, Lucknow, Madras, Mysore, Osmania, Paris, Patna, Sri Venkateswara

Honorary Member :

Deutsche Academy of Munich

Hungarian Academy of Sciences

Indian Science Congress Association and several other Indian Science Organisations.

Royal Irish Academy

Royal Philosophical Society, Glasgow

Zurich Physical Society

Honorary Fellow :

Optical Society of America

Minerological Society of America

Foreign Associate :

Academy of Sciences, Paris

Foreign Member :

Academy of Sciences, USSR

Honorary Member :

Academy of the Socialist Republic of Romania Catgut Acoustical Society.

General President :

Indian Science Congress, 1929

President :

Indian Academy of Science, 1934-1970.

Appendix-II

Molecular Scattering of Light

The Colour of the Sea

In the history of science, we often find that the study of some natural phenomenon has been the starting point in the development of a new branch of knowledge. We have an instance of this in the colour of skylight, which has inspired numerous optical investigations, and the explanation of which, proposed by the late Lord Rayleigh, and subsequently verified by observation, forms the beginning of our knowledge of the subject of this lecture. Even more striking, though not so familiar to all, is the colour exhibited by oceanic waters. A voyage to Europe in the summer of 1921 gave me the first opportunity of observing the wonderful blue opalescence of the Mediterranean Sea. It seemed not unlikely that the phenomenon owed its origin to the scattering of sunlight by the molecules of the water. To test this explanation, it appeared desirable to ascertain the laws governing the diffusion of light in liquids, and experiments with this object were started immediately on my return to Calcutta in September 1921. It soon became evident, however, that the subject possessed a significance extending far beyond the special purpose for which the work was undertaken and that it offered unlimited scope for research. It seem indeed that the study of light-scattering might carry one into the deepest problems of physics and chemistry and it was this belief which led to the subject becoming the main theme of our activities at Calcutta from that time onwards.

Nobel Lecture December 11, 1930

The Theory of Fluctuations

From the work of the first few months, it became clear that the molecular scattering of light was a very general phenomemon which could be studied not only in gases and vapours but also in liquids and in crystalline and amorphous solids, and that it was primarily an effect arising from molecular disarray in the medium and consequent local fluctuations in its optical density. Except in amorphous solids, such molecular disarray could presumably be ascribed to thermal agitation, and the experimental results appeared to support this view. The fact that molecules are optically anisotropic and can orientate freely in liquids was found to give rise to an additional type of scattering. This could be distinguished from the scattering due to fluctuations in density by reason of its being practically unpolarised, whereas the latter was completely polarised in the transverse direction. The whole subject was critically reviewed and the results till then obtained were set out in an essay published by the Calcutta University Press in February 1922.

The various problems requiring solution indicated in this essay were investigated with the aid of a succession of able collaborators. It is possible to mention briefly only a few of the numerous investigations which were carried out at Calcutta during the six years, 1922 to 1927. The scattering of light in fluids was studied by Ramanathan over a wide range of pressures and temperatures with results which appeared to support the "fluctuation" theory of its origin. His work also disclosed the remarkable changes in the state of polarisation which accompany the variations of intensity with temperature in vapours and in liquids. Liquid mixtures were investigated by Kameswara Rao, and furnished optical proof of the existence in such systems, of simultaneous fluctuations of density, composition, and molecular orientation. Srivastava studied the scattering of light in crystals in relation to the thermal fluctuations of density and their increase with temperature. Ramdas investigated the scattering of light by

liquid surface due to thermal agitation, and established a relation between surface-tension and surface-opalescence. He also traced the transition from surface-opalescence to volume opalescence which occurs at the critical temperature. Sogani investigated X-ray diffraction in liquids, in order to connect it with their optical behaviour, and test the application of fluctuation theory to X-ray scattering.

The Anisotropy of Molecules

As stated above, the state of polarisation of the light scattered in fluids is connected with the optical anisotropy of the molecules. Much of the work done at Calcutta during the years 1922-1927 was intended to obtain data concerning this property and to establish its relations with various optical phenomena. Krishnan examined a great many liquids, and by his work showed very clearly the dependence of the optical anisotropy of the molecule on its chemical constitution. Ramakrishna Rao studied the depolarisation of scattered light in a very large number of gases and vapours, and obtained information of high importance for the progress of the subject. Venkateswaran studied the scattering of light in aqueous solutions to find the influence on it of electrolytic dissociation. Ramachandra Rao investigated liquids having highly elongated molecules and also highly polar substances over a wide range of temperatures, and discovered the influence of molecular shape and molecular association on the depolarisation of scattered light in liquids.

The interpretation of the observations with liquids involved the development of a molecular theory of light scattering in dense media which was undertaken by Ramanathan, myself and Krishnan. A revised opalescence formula was derived which differed from that of Einstein and yielded results in better agreement with observation. Krishnan and myself also published a series of investigations showing how the optical anisotropy of the molecules deduced from light-scattering could be utilised to interpret the optical and dielectric behavious of fluids, and also the electric, magnetic, and mechanical birefringence exhibited by them. The

conclusions derived from these studies enabled a connection to be established between the molecular anisotropy observed in fluids and the optical, electric, and magnetic aeolotropy exhibited by solids in the crystalline state.

A New Phenomenon

The investigations referred to above were in the main guided by the classical electromagnetic theory of light, the application of which to the problems of light-scattering is chiefly associated with the names of Rayleigh and of Einstein. Nevertheless, the possibility that the corpuscular nature of light might come into evidence in scaterring was not overlooked and was in fact elaborately discussed in the essay of February 1922, which was published atleast a year before the well-known discoveries of Compton on X-ray scattering. While our experiments in the main appeared to support the electromagnetic theory of light, evidence came to hand at a very early stage of the investigations of the existence of a phenomenon which seemed to stand outside the classical scheme of thought. The scattering of light in transparent fluids is extremely feeble, much weaker in fact than the Tyndall effect usually observed in turbid media. It was experimentally discovered that associated with the Rayleigh-Einstein type of molecular scattering, was another and still feebler type of secondary radiation, the intensity of which was of the order of magnitude of a few hundredths of the classical scattering and differed from it in not having the same wavelength as the primary or incident radiation. The first observation of this phenomenon was made at Calcutta in April 1923 by Ramanathan who was led to it in attempting to explain why in certain liquids (water, ether, methyl and ethyl alcohols), the depolarisation of scattered light varied with the wavelength of the incident radiation. Ramanathan found that after exhaustive chemical purification and repeated slow distillation of the liquid in vacuum, the new radiation persisted undiminished in intensity, showing that it was a characteristic property of the substance studied and not due to any fluorescent impurity. Krishnan observed a similar effect in many

other liquids in 1924, and a somewhat more conspicuous phenomenon was observed by me in ice and in optical glasses.

The Optical Analogue of the Compton Effect

The origin of this puzzling phenomenon naturally interested us, and in the summer of 1925, Venkateswaran attempted to investigate it by photographing the spectrum of the scattered light from liquids, using sunlight filtered through colour screens, but was unable to report any decisive results. Ramakrishan Rao in his studies on the depolarisation of scattering during 1926 and 1927 looked carefully for a similar phenomenon in gases and vapours, but without success. This problem was taken up again by Krishnan towards the end of 1927. While his work was in progress, the first indication of the true nature of the phenomenon came to hand from a different quarter. One of the problems interesting us at this time was the behaviour in light-scattering of highly viscous organic liquids which were capable of passing over into the glassy state. Venkateswaran undertook to study this question, and reported the highly interesting result that the colour of sunlight scattered in a highly purified sample of glycerine was a brilliant green instead of the usual blue. The phenomenon appeared to be similar to that discovered by Ramanathan in water and the alcohols, but of much greater intensity, and therefore, more easily studied. No time was lost in following up the matter. Tests were made with a series of filters transmitting narrow regions of the solar spectrum and placed in the path of the incident beam, which showed that in every case the colour of the scattered light was different from that of the incident light, and was displaced from it towards the red. The radiations were also strongly polarised. These facts indicated a clear analogy between the empirical characters of the phenomenon and the Compton effect. The work of Compton had made familiar the idea that the wavelength of radiation could be degraded in the process of scattering, and the observations with glycerine suggested to me that the phenomenon which had puzzled us ever since 1923

was in fact the optical analogue of the Compton effect. This idea naturally stimulated further investigation with other substances.

The chief difficulty which had hitherto oppressed us in the study of the new phenomenon was its extreme feebleness in general. This was overcome by using a seven-inch refracting telescope in combination with a short-focus lens to condense sunlight into a pencil of very great intensity. With these arrangements and using complementary light-filters in the path of the incident and scattered beams, as was done by Ramanathan in 1923, to isolate the modified radiations, it was found that they could be readily observed in a great many liquids, and that in many cases they were strongly polarised. Krishnan, who very materially assisted me in these investigations, found at the same time that the phenomenon could be observed in several organic vapours, and even succeeded in visually determining the state of polarisation of the modified radiations from them. Compressed gases such as Co_2 and N_2o, crystalline ice, and optical glasses also were found to exhibit the modified radiations. These observations left little doubt that the phenomenon was really a species of lights scattering analogous to the Compton effect.

The Spectroscopic Characters of the New Effect

Thanks to the vastly more powerful illumination made available by the seven inch refractor, the spectroscopic examination of the effect which had been abandoned in 1925 as indecisive, now came within the reach of direct visual study. With a Zeiss cobalt-glass filter placed in the path of the incident beam and one or other of a series of organic liquids as the scattering substance, a band in the blue-green region was observed by me in the spectrum of the scattered light, separated by a dark interval from the indico-violet region transmitted by the filter. Both of these regions in the spectrum became sharper when the region of transmission was narrowed by the insertion of an additional filter in the incident beam. This suggested the employment, instead of sun-light, of the highly monochromatic radiations given by a mercury arc in combination with a condenser of large aperture and a cobalt-glass

filter. With these arrangements the spectrum of the scattered light from a variety of liquids and solids was visually examined, and the startling observation was made that the spectrum generally included a number of sharp lines or bands on a diffuse background which were not present in the light of the mercury arc.

The quartz mercury lamp was so powerful and convenient a source of monochromatic illumination that, at least in the case of liquids and solids, photographing the spectrum of scattered light was found to present no extraordinary difficulties. The earliest pictures of the phenomenon were in fact taken with a portable quartz spectrograph of the smallest size made by the firm of Hilger. With a somewhat larger instrument of same type, Krishnan obtained very satisfactory spectrograms with liquids and with crystals on which measurements of the desired precision could be made, and on which the presence of lines displaced towards the violet was first definitely established. The experimental difficulties were naturally greater in the case of gases or vapours, though they could be lessened by working with the substance under pressure. With an improvised instrument of large aperture Ramdas obtained the first spectrograms with a gaseous substance (ether vapour) at atmospheric pressure.

In interpreting the observed phenomena, the analogy with the Comption effect was adopted as the guiding principle. The work of Compton had gained general acceptance for the idea that the scattering of radiation is a unitary process in which the conservation principles hold good. Accepting this idea it follows at once that, if the scattering particle gains any energy during the encounter with the quantum, the latter is deprived of energy to the same extent, and accordingly appears after scattering as radiation of diminished frequency. From thermodynamic principles it follows that the reverse process should also be possible. Adopting these ideas, the actual observations could be interpreted, and the agreement of the observed displacements with the infra-red frequencies of the molecules made it clear that the new method opened up an illimitable field of experimental research in the study of the structure of matter.

Interpretation of the Effect

It appears desirable to emphasize that though the conservation principle of Compton is useful in interpreting the effects disclosed by experiment, it is by itself insufficient to explain the observed phenomena. As is well known from studies on molecular spectra, a gaseous molecule has four different species of energy of increasing orders of magnitude, namely those corresponding to translatory motion, rotation, vibration, and electronic excitation. Each of these, except the first, is quantized and may be represented by an integer in an extended sequence of quantum numbers. The aggregate energy of a molecule may, therefore, assume any one out of a very large number of possible values. If we assume that an exchange of energy occurs in the collision between the molecule and the quantum, and limit ourself to the case in which the final energy of the molecule is less than that of the incident quantum, we arrive at the result that the spectrum of the scattered light should contain an immense number of new lines and should in fact rival in its complexity the band spectrum of the molecule observed in the emission or absorption of light. Nothing more different from what is actually observed can be imagined than the foregoing picture. The most conspicuous feature revealed by experiment is the beautiful simplicity of the spectra of even complicated polyatomic molecules obtained in light-scattering, a simplicity that is in striking contrast to the extreme complexity of their emission or absorption spectra. It is this simplicity that gives to the study of light-scattering its special significance and value. It is clear that the effect actually observed was not and could not have been foreseen from an application of the conservation principles.

The general principle of correspondence between the quantum and classical theories enunciated by Niels Bohr enables us, on the other hand, to obtain a real insight into the actual phenomena. The classical theory of light scattering tells us that if a molecule scatters light while it is moving, rotating or vibrating, the scattered radiations may include certain frequencies different from those of the incident waves. This classical picture, in many respects, is suprisingly like

what we actually observe in the experiments. It explains way the frequency shifts observed fall into three classes, translational, rotational and vibrational, of different orders of magnitude. It explains the observed selection rules, as for instance, why the frequencies of vibration deduced from scattered light include only the fundamentals and not the overtones and combinations which are so conspicuous in emission and absorption spectra. The classical theory can even go further and give us a rough indication of the intensity and polarisation of the radiations of altered frequency. Nevertheless, the classical picture has to be modified in essential respects to give even a qualitiative description of the phenomena, and we have, therefore, to invoke the aid of quantum principles. The work of Kramers and Heisenberg, and the newer developments in quantum mechanics which have their roots in Bohr's correspondence principles, seem to offer a promising way of approach towards an understanding of the experimental results. But until we know much more than we do at present regarding the structure of molecules, and have sufficient quantitative experimental knowledge of the effect, it would be rash to suggest that they afford a complete explanation of it.

The Significance of the Effect

The universality of the phenomenon, the convenience of the experimental technique and the simplicity of the spectra obtained enable the effect to be used as an experimental aid to the solution of a wide range of problems in physics and chemistry. Indeed, it may be said that it is this fact which constitutes the principal significance of the effect. The frequency differences determined from the spectra, the width and character of the lines appearing in them, and the intensity and state of polarisation of the scattered radiations enable us to obtain and insight into the ultimate structure of the scattering substance. As experimental research had shown, these features in the spectra are very definitely influenced by physical conditions, such as temperature and state of aggregation, by physico-chemical conditions, such as mixture, solution, molecular association and polymerization, and most essentially by chemical consitution. It

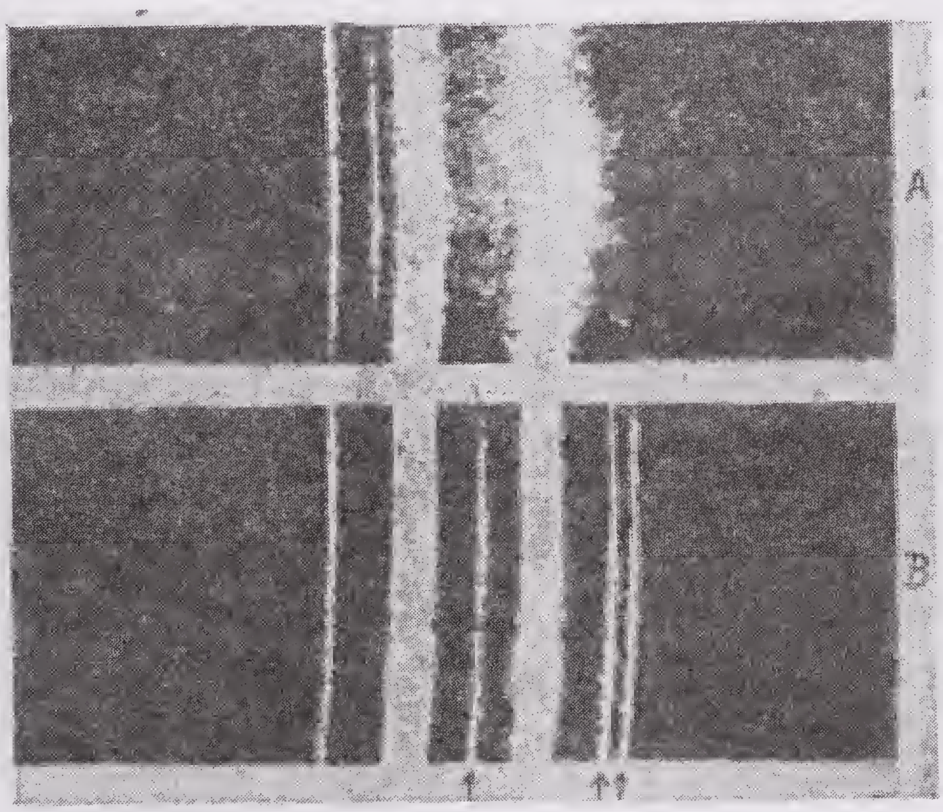
follows that the new field of spectroscopy has practically unrestricted scope in the study of problems relating to the structure of matter. We may also hope that it will lead us to a fuller understanding of the nature of light, and of the interactions between matter and light.

Some Concluding Remarks

From a physical point of view, the quantitative study of the effect with the simplest molecules holds out the largest hope of fundamental advances. The beautiful work of McLennan with liquified gases, and of R.W. Wood and Rasetti are pioneer investigations in this field which command the highest admiration. The quantitative study of the effect with crystals of the simplest possible chemical constitution is naturally of great importance. The case of the diamond, which has been investigated by Ramaswamy, Robertson, and Fox, and with especial completeness by Bhagavantam, is of special interest. Very surprising results have been obtained with this substance, which may be the pathway to a fuller understanding of the nature of the crystalline state. I should also like to draw attention to the work of Krishnamurti, who has traced a remarkable dependence of the intensity of the spectral lines observed in scattering on the nature of the chemical bond, and followed by transition from the homopolar to the heteropolar type of chemical combination. Krishamurti's observation that the paramagnetism of crystals apparently influences the observed intensity of the displaced lines is one of the most remarkable findings ever made in this new field of research.

Raman Effect in Benzene

In the facing Art Plate are two spectrograms to illustrate the Raman Effect in liquid benzene. The upper spectrogram is that of the incident light and the lower that of the scattered light. These spectrograms were taken with a small Hilger Quartz Instrument using light from a quartz mercury are filtered through pottassium permaganate solution.



Incident Radiation

Scattered Radiation

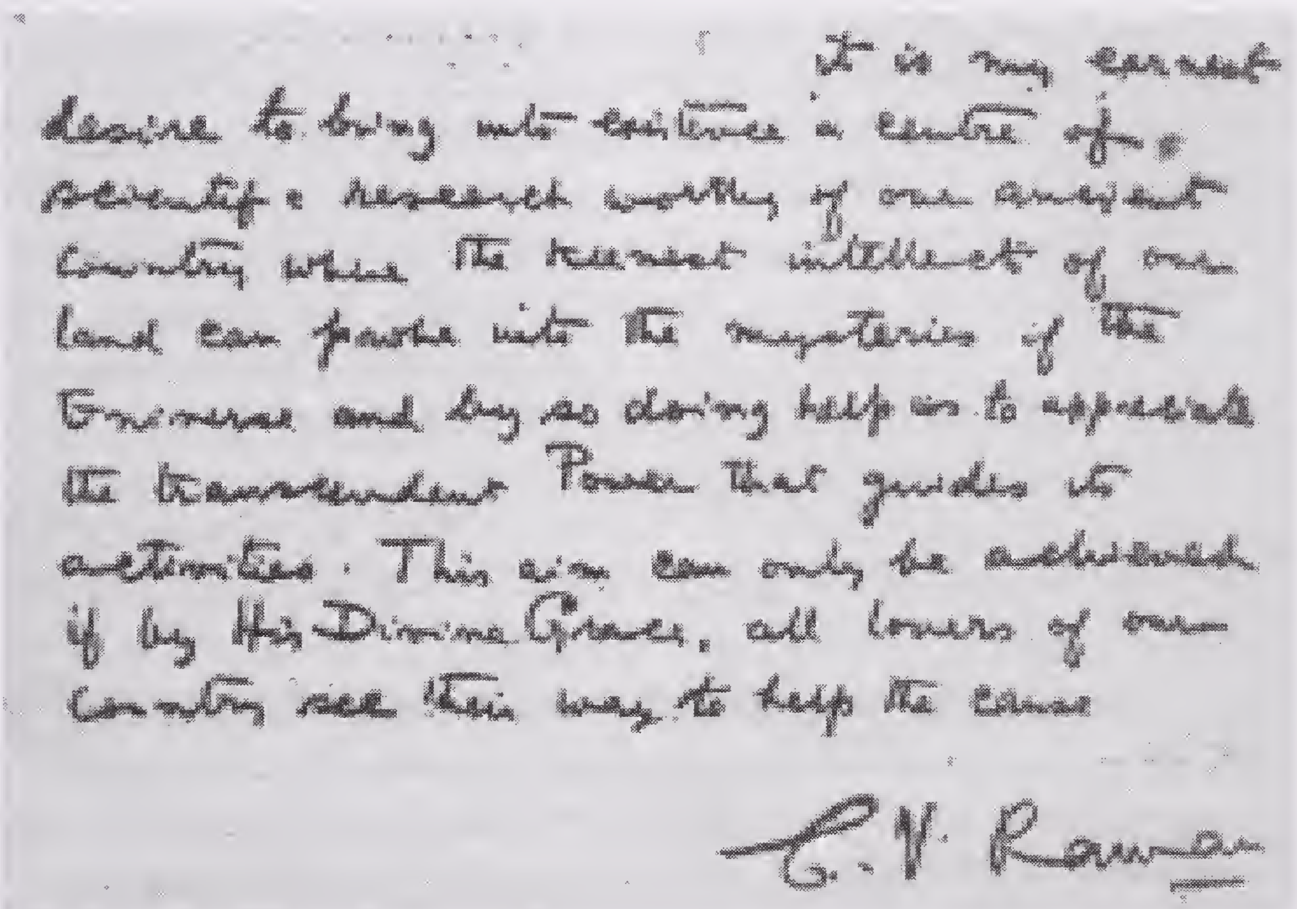
The wavelengths of the two prominent lines in the incident spectrum are 4046 AU and 4358 AU. The new lines in the scattered spectrogram are the lines of the "New Radiation"–the Raman Effect. Their positions show the change in the wavelength suffered by the scattered radiation as a result of the benzene molecules absorbing an amount of energy determined by their characteristic

internal oscillations. In this spectrogram, two lines with changed frequencies are clearly seen. They correspond to the two molecular oscillations of benzene which give rise to infra red absorption in the wavelengths of 10.2 microns and 8.5 microns. Raman Effect thus provides an easy method of measuring infra-red absorption of molecule, the frequency of their characteristic oscillations, and from that the strengths of the molecular bonds and so on and so forth.

The spectrograms are reproduced from Raman's very first lecture : *A New Radiation,* delivered at Bangalore on March 16, 1928, a couple of weeks after the effect was seen by him on February 28, 1928, using a direct vision spectrometre.

Appendix-IV

The principal objective of the Raman Research Institute, Bangalore, in Raman's own handwriting. Obviously, Raman was not an atheist.



It is my earnest
desire to bring into existence a centre of
scientific research worthy of our ancient
country where the keenest intellects of our
land can probe into the mysteries of the
Universe and by so doing help us to appreciate
the transcendent Power that guides its
activities. This aim can only be achieved
if by His Divine Grace, all lovers of our
country see their way to help the cause

C. V. Raman

Appendix-V

Prof. C.V. Raman's lecture on "WHY THE SKY IS BLUE?" delivered on December 22, 1968, at the foundation stone laying ceremony of the Community Science Centre, Ahmedabad.

When I was asked to choose a scientific subject for my lecture I had no difficulty at all in choosing the subject of "Why the sky is blue." Fortunately, nature has been kind today: as I look up and see, the sky is blue; not everywhere, as there are many clouds. I chose this subject for the simple reason that this is an example of something you do not have to go to the laboratory to see. Just look up, look at the sky. And I think it is also an example of the spirit of science. You learn science by keeping your eyes and ears open and looking around at this world. The real inspiration of science, at least to me, has been essentially the love of nature. Really, in this world, wherever we see, we see all kinds of miracles happening in nature. To me, everything I see is something incredible, something absolutely incredible. We take it all for granted. But I think the essence of the scientific spirit is to look behind and beyond and to realise what a wonderful world it is that we live in. And everything that we see presents to us not a subject for curiosity, but a challenge, a challenge to the spirit of man to try to understand something of this vast mystery that surrounds us.

Science continually attempts to meet this challenge to the spirit of man. And the great problem today, which Dr. Sarabhai has addressed himself to, is how to rouse the younger generation of our country to meet this great challenge before us, once again to

build up India into a great centre of knowledge and learning and endeavour. Well, I wish you all success. Now let me turn back to my problem, "Why the sky is blue?"

I raised this question because it is an easy subject. I only have to look up and see that the sky is blue. But why is it blue? The interesting point is that it is easy to answer that question in a casual way. If you ask a botanist, why are leaves green? He murmurs, 'Chlorophyll'. Finished. You see, all scientific questions can be disposed of in that summary fashion, in one or two words. You can surely pass your examinations with that kind of answer, but that is not the real answer. As I said before, the scientific challenge of nature is to think, not only to discover but to think, to think continually and to try to penetrate this mystery: "Why is it blue?" That is a very interesting problem, because two things are there. The sky is there and I am here. I see it is blue. It is the human brain and the human mind as well that are involved in this problem. Now suppose we put this problem before the young people. Don't read any book about it, don't ask your teacher. Let us sit down and try to think out this problem; why is the sky blue? Look at it as if it is a completely new scientific problem about which nobody has troubled himself before. You sit down and think it out and you will find it a most exciting thing to ask yourself that question and see if you can discover the answer for yourself. Now I will put it to you in this way. The best way to answer a question is to ask another. At night, we all see the stars. On a fairly clear night you see the stars twinkling in the sky. Why are the stars not visible in day time? Please ask yourself this question. Well, the reason obviously is that the earth, as a modest lady, has hidden herself under a veil. The sky is a veil which she has thrown around us. We cannot see the stars during the day, because the veil hides the stars. And what is this veil? The veil obviously is the atmosphere of the earth. The same veil which at night is so transparent that we can see the faintest star and the milky way is covered up in day-time. Obviously, it is the atmosphere which is

the veil. And we see the sky as blue only because we have not got other thicker veils like these clouds. You see, for examdle, those clouds high in the blue sky. Obviously, therefore, for the sky to be really blue, there must be nothing else, no clouds and perhaps no dust. The clearer the sky is, the bluer it is. So the sky is not always blue; it is sometimes blue and sometimes not blue at all. So that the mere looking at the sky enables us to understand the condition of the atmosphere.

Let me say one thing more. Obviously, the sky and the atmosphere are lit up by the sunlight. Sunlight is passing through this great column of air and obviously it is the atmosphere, something that is transparent and invisible at night, that is seen to us by the light–sunlight–passing through the atmosphere. Now I want you to ask yourself another question. I don't know if any of you have had the curiosity to look at the clear sky on a full-moon night. You know that moonlight is only the sunlight incident on the moon and is diffused or reflected. I don't know if any of you have really watched the sky on a clear full-moon night. You will be astonished to find that the sky is not blue. It appears pale, you just see some light and you see some of the stars even under the full-moon night. You will be astonished to find that the sky is not blue. Why is it that the sky which appears blue in sun-light, does not appear blue in moonlight? The answer obviously is: the illumination is far less powerful. You don't require to be much of a mathematician to calculate the ratio of the intensities of full moon light and sunlight. I present it to some young mathematician to sit down and work out. How big is the moon? What should be the brightness of moonlight? It is a little astronomical problems. Rough arithmetic would tell you that moonlight is something like half a millionth part as bright as sunlight; you would think, it is terribly small. But moonlight, when it is there seems very bright though it is only half a millionth part of the brightness of sunlight. Why does it look so bright? Well, the eyes have got accustomed to much lower levels of illumination. So moonlight appears very bright, but not so bright, as to veil all the stars. But the sky, it does not

appear blue. So, this comparison of sunlight and moonlight bring to our notice a very remarkable fact. It is an absolutely fundamental aspect of human vision that to perceive colour, you must have a high level of illumination. The sky is blue, merely because sunlight is brilliant; moonlight is much less brilliant and so you don't perceive colour. This is a principle which perhaps is not so widely appreciated as it ought to be. Colour is only perceived at high levels of illumination. The higher the illumination the brighter are and the colours. You go down to low levels of illumination, say, a millionth part, half a millionth or a hundred thousandth part of sunlight, the sense of colour disappears. Now this is a very fundamental fact of human vision, which simply comes out of nothing else but just observation and thinking, that's all. I can go on giving any number of illustrations. Perhaps the most striking illustration emerges when you look at the stars or such objects as the Orion nebula through small telescopes. Let me say here and now, my belief that there is no science so grand, so elevating, so intensely interesting as astronomy. It is amazing to see how many people high up have never seen the sky through the telescope. I want to tell them something which is absolutely incredible; Nothing more than a pair of binoculars, a good pair of binoculars is need to educate oneself in the facts of astronomy. I think a man who does not look at the sky even through that modest equipment–a pair of binoculars–cannot be called an educated person, because he has missed the most wonderful thing and that is the universe in which he lives. You must have a look at it. You don't see much of it, but you see a little and even this little is enough to elevate the human soul and make us realise what a wonderful thing this world is.

I come back now to the problem of the blue sky, I want to pose to you a very difficult question. Why is it that we perceive the blue colour only under intense illumination in sun-light, and not in moonlight? I will by pass that and come back to the question : Why is the sky blue? Well, we all know that white light is composed of all the colours in the spectrum. You divide white light into various colours; you start with deep red at one end, light

red, orange, yellow, green, blue and violet, so on, the whole range of colours. When I look at the sky, I see only the blue ; what has happened to the rest of the spectrum? This is the basic question. The question becomes a very pressing one when I remark that when we actually spread out sunlight into a spectrum, the blue part of it is the least intense part. Less than 1.40th of the whole energy of the brightness of the sunlight appears in the blue of the spectrum It has simply vanished. It is not there at all. You can look very very hard and try to see if you can see any red or yellow or green in blue sky. We don't see it. The blue has just masked the rest of the spectrum. This is a very remarkable fact. If you watch the sky on some occasions, you get great masses of while clouds, what they call, the cumulus clouds not huge things, just little bunches. It is a beautiful sight to see the blue sky and these little masses soaring above. I have derived great satisfaction in just doing nothing at all and looking at these masses of clouds and the blue sky. The interesting point is precisely when you have the clouds moving about that the sky is bluest. What it means is that these cumulus clouds in the course of their formation just cleaned up the rest of the atmosphere. They take up the dust particles and concentrate them on the while clouds. The rest is left nice and clean. You see the beautiful blue view against the brilliant white, it is a very lovely sight. A sight for the Gods; only you don't bother to look at it because it is so common. You may ask me, how is the cleaning process accomplished? Now here is a wonderful story. When I ask the young people, "What is the clouds?" "Oh ! Sir, it is steam". The usual answer you get is that the cloud is steam, but it is nothing of the sort. The cloud consists of particles and what looks to us as great masses of white clouds are just droplets of water. Water is heavy but why does it not fall down? We find it floating in the air! You see that is another problem. Already I am going from one problem to another. We ask ourselves, what is a cloud? Why is it floating in the air? The moment you ask the question, "Why the sky is blue?" you go deeper and deeper into some of the deepest problems of Physics. Now the interesting point

is this you cannot have a cloud unless you have dust particles about which it can form.

There must be particles of some sort, may be very small, may be very large. They call it in learned language ‘Nuclei’. If there is no dust in the air, there will be no cloud and no rain. You see, how from the blue sky, we have got on to the origin of rain, rainfall and so on. One thing leads to another. That is the essence of science. You must go deeper where it leads you. You cannot go thus far and no further. The moment you raise a question, another question arises, then another question, so on and so forth. Ultimately, you find that you have to travel the whole field of science before you get the answer to the question: Why the sky is blue? So I told you this fact about the clouds. Well, I should say the cloud cleans up the atmosphere. Cloud forms and them leaves the atmosphere clean, comparatively free from dust particles and other nuclei and that is why the sky is blue. So we come down at last to getting some kind of answer to the problem. The sky is blue because the atmosphere is clean and free from dust and all nuclei. The clearer it is, the bluer it looks, provided there is enough light. So you come somewhere near the answer to the question. What is it you are able to see? The fact is that when we see a blue sky, we see the atmosphere of the earth, the gases of the atmosphere, they diffuse the light and we see the blue light of the sky. But still we are far from the answer.

I told you that blue is only 1/40th part of the sunlight. What happens to the rest of the light, the sunlight? That is the question. Now this question can be answered in the following fashion. You look at the white cloud and look at the blue sky. You can compare them with the help of a pocket spectroscope and you find strangely enough that you have to look very very carefully before you find any difference in the spectrum of the blue sky and the spectrum of the white cloud. White cloud is certainly very much brighter. But so far as spectrum is concerned, you see in the blue sky and in the cloud the same spectrum. It also starts with the red end and goes

on till the blue. But in one case you see the blue, in the other case you see the white. And with great trouble, you look very carefully. You see that there is some difference in the relative brightness. You can see the yellow and the red, not so bright relatively. Mind you, it is a mental calculation. You see the relation of brightness between the blue part of the sky, the blue part of the spectrum and the violet part and the rest of the spectrum. Relatively to the red, the yellow and the green, the blue and violet are stronger in the scattered light, in the diffused light of the blue sky. Still you are very far from the answer. It does not explain why don't we see the rest of the spectrum. Actually in the blue sky the green and the yellow and the red are still there, they are still far brighter, perhaps not so, perhaps not 40 times but perhaps ten times brighter than the blue. Then why do we see the blue and why don't we see the rest? Here again you come across an extremely difficult question to answer. The actual brightness of the blue part of the spectrum in skylight is still much smaller than the brightness of the rest of the spectrum but we don't perceive that part of the spectrum. Now this is very simple and very surprising. But there is a nice little experiment which, perhaps one day, will be shown at the Science Centre which will enable you to see at least that it is not an exceptional phenomenon. It is one of the most fundamental facts of human vision that the blue part of the spectrum in spite of its weakness dominates the spectrum in certain conditions and plays a role tremendously far more important than its actual brightness warrants. Now the experiment is the following. It is a very easy experiment. You take water and put a little copper sulphate in it and then put excess ammonia in it. You will get a solution called cuprammonium. If it is very strong it will transmit only deep violet light. Put it in a cell. You go on adding water in the cell and look at the colour of the bright lamp and see that the following thing happens. The deep violet changes into blue. The blue changes to a lighter blue and so on. But till the very last, it remains blue. In the spectrum of the light the solution is transmitting red light, green light, not of course yellow. Lot of light comes through the spectrum

and the blue is still only a minor part of the whole. Whatever light comes through the spectrum you cannot see and you cannot even imagine any other colour coming through. And the reason for it is as follows. If you examine the transmitted light through a spectroscope you will find that the yellow part of the spectrum is diminished by the influence of cuprammonium. It absorbs and cuts out the small part of the width of the spectrum, but a very important part and that very important part is the yellow of the spectrum. Never mind how it absorbs the yellow part and controls the colour. The light is blue simply because the yellow is absorbed and the blue comes into vision. If you take the whole spectrum and if you reduce the strength of the yellow part of the spectrum, at once you find the blue part of the spectrum and the blue colour dominates. This is again a fact of physiology. If you want any colour whatsoever to be shown, you must take out the yellow. Take for example that red carpet, which has been spread in my honour. I suppose. You look at it through a spectroscope. I can tell you beforehand, there will be no yellow in it at all. To get any colour, red, green or blue, you must take out the yellow. Yellow is the deadly enemy of colour. All other colours. I mean. Look at the green leaf. All the leaves are green, not because of the presence of chlorophyll–the chlorophyll has a strong absorption of red, no doubt. But the real factor which makes the colour green is the fact that the yellow is taken off. Chlorophyll has enough absorption of this yellow to reduce the strength of yellow. Well, I examined silks for this, Bangalore is a great place for silk manufacture. I managed to purchase about 25–30 blouse pices. I got them to verify the proposition that all brilliant colours requires the suppression of the yellow region of the spectrum. Look at the rice field. It is wonderful. Look at the rice field with a spectroscope.

It looks very much like the spectrum of the blue sky. But the only visible difference you can actually see at a glance between the blue sky and the green rice field is that the blue part of the spectrum has been cut off and that is produced by the so-called carotenoid pigments that are present here, which cut off the blue;

the rest of the spectrum looks almost alike. But if you look very carefully you will see that in the colour of the rice field, you do not get the yellow. The removal of yellow is essential, before you can perceive the leaves as green. You see always this predominance of the yellow. On the contrary, if the yellow is taken off, the blue dominates. If you don't take off the yellow, the yellow dominates. The two are contradictory and they are enemies to each other. The fact is that you can divide–the physical explanation is deeper still–you can divide the whole spectrum into two parts. The division is just where the blue ends; that part of the spectrum extending to green, yellow, orange and red amounts only to yellow. The other parts of the spectrum summed up amounts to blue. Now if you take off this or reduce this you get the other. This is the real explanation of the blue colour of the sky and is very significant. You reduce–not that you abolish–the intensity of the yellow in the spectrum and of course of the green and the red. It is the reduction of the yellow of the spectrum that is to say the predominance of the blue which is responsible for the blue light of the sky. Well, one can carry further and say that it is the reduction of yellow that is basic. And why is it reduced? So here comes the second part of it. I could have started with that and said "Why is the sky blue?" "Oh, the scattering of light by the molecules of the atmosphere." I could have dismissed the whole lecture in one sentence. I could have said just as the botanist says "Why is it green?" "Just chlorophyll." I could have said "Why is the sky blue?" "Scattering of light by the molecules of the atmosphere." One sentence. "Then sir", you would ask me, "Why all this lecture?" Because, my young friends, I want you to realise that the spirit of science is not finding short and quick answers. The spirit of science is to delve deeper–and that is what I want to bring home to my audience–deeper. Don't be satisfied with the short and ready quick answers. You must never be content with that; you must look around and think and ask all sorts of questions; look round the problem and search, and search and go on searching. In the course of time you will find some of the truths, but you never reach the end. The end, as I told

you, is the human brain, but that is very far away yet. This is the spirit of science. I should give you an illustration of how by pursuing a simple question. I can go on talking to you as if I have just begun, the real subject of my lecture: "Why the sky is blue?" "The sky is blue because the illumination of the sky light is due to the scattering of light by the molecules of the atmosphere." Now this is a discovery which came rather slowly. The person who first stated this explanation was the late Lord Rayleigh.

I think that dreams are the best part of life. It is not the realisation, but the anticipation; I am going to make a discovery tomorrow, that makes a man of science work hard, whether he makes the discovery or not. And this is what I want to emphasize once again. Science is essentially and entirely a matter of the human spirit. What does a poet do? What does a painter do? What does a great sculptor do? He takes a block of marble, chips, goes on chipping and chipping. At the end of it, he produces the dream in the marble. We admire it. But my young friends please remember what a tremendous amount of concertrated effort has gone into producing that marble piece. It is the hope of realising something which will last for ever which we will admire for ever that made him undertake all that work. Essentially, I do not think there is the least difference whatever between the urge that drives a man of science to devote his life to science, the search for knowledge and the urge that makes workers in other fields devote their lives to achieving something. The greatest thing in life is not the achievement but it is the desire to achieve. It is the effort that we put in, that ultimately is the greatest satisfaction. Effort to achieve something in the hope of getting something; let it come or not come, but it is the effort that makes life worth living and if you don't feel the urge towards the search for knowledge, you can never hope to be a man of science. You can perhaps get a job in some of the departments, get a nice comfortable salary, in which you don't have to do anything except to wait for the monthly cheque; but that is not science. The real business of a scientific

man is to try to find something real and to look forward to the acquirement of knowledge.

Having said all this, may I again come back to the blue sky? I have not finished yet. In fact, to tell you the honest truth. I have only just begun my lecture. Why is it that the molecules of the air scatter light? The obvious thing is this, as I told you, the long waves in the spectrum–I am using the language of wave optics–the long waves of the red, yellow and the green are scattered less in the diffused light and the rest quite strongly, with the result that the eye perceives this and not that. Now why is that? The answer is very obvious. The molecules of the atmosphere are extremely small in size, incredibly small compared with what is the standard of comparison, the wave length of light. The same thing you notice, for example, if you look at a big lake. The wind blows on the waves and you have a piece of cork or wood floating on it. You see the wood trembling. Why? Because the size of the wood is comparable with the size of the waves. But suppose you had a big boat going on the lake; I don't know how big the boat can be, but you see that the big boat is not disturbed so much as the small particle. It is the relationship between the size of the disturbance and the size of the particle that determines the effect the waves produce on the particles and vice versa, the effect produced by the particles on the waves. This is the basic principle which results in the scattering of the shorter waves by preference. You can show that by any number of experiments in the laboratory; for that, you don't require molecules of air. You require just some water and put in it some substance like bit of soap. You can also make the experiment with smoke; particles small enough will scatter the shorter waves by preference. But you don't get the real rich blue colour unless the particles are extremely small. And as I have already indicated, you must have adquate illumination. Unless the illumination is strong enough, the sensation will be just the palest of pale blues. Now I have come from the scattering of blue sky to the study of molecules. And there the subject begins and it goes

on. In fact, I started the subject in the year 1901. What I told you was known pretty well except the vision part of which I have spoken about. That is my most recent work, but what I spoke about molecules and so on was all known in 1921. At that time, we thought it was finished. Today, we know that the faculty of vision and the quality of vision play an immense role in the subject.

The subject of my lecture is not the blue of the sky, but, as you must have all understood by this time, it is the spirit of science. What is science? And how can we in this country hope to advance science? How can we try to really make ourselves worthy of our ancestors in the past? That is the real topic of my lecture. It is only the peg to hang the subject upon. Well, the story begins there. The question is how does light interact with molecules and what happens with molecules and what are molecules and so on. Science never stops. It is going on. The more you find, the more appears that you have to find. That is the attraction of science, provided you are not distressed too much by other people getting in front of you. Don't bother about them. The real point is that it is an endless quest and every new discovery opens new paths for discovery. New questions arise requiring new answers.

But then, I cannot give this lecture without making some reference at least as to how all this I am talking about is united up with meteorology all the time. But the real interest in the subject is not in meteorology at all. The real interest in the subject is the scattering of light which is the most powerful weapon we have today for understanding the ultimate nature of the molecules of the air. Your can count the molecules. You can make the experiment in the laboratory. It is an experiment which every student of science ought to have seen. You take a glass bottle, a flask and a cork and get all the dust out of it and send a beam of light, it may be sunlight, it may be any thing else but see that the beam of the light goes through the air. You can see the air. The air is not such a transparent, colourless gas; it is not invisible. You can make air visible by means of this scattered light. This is a very simple experiment and ought

to be seen by every student of science at least once in his life time. You can see air. You can see any gas. You can see any vapour, by the strength of the light diffused by the individual particles. And the more particles you have, the stronger the diffusion. From the strength of the diffusion, you can actually count the number of molecules. I use the word counting, not like one, two, three, four; it is a sort of different type of counting. When I was in the currency office, they used to count the rupees. You know what they did; they did not count the rupees. They counted the bags; they weighted the bags; each bag was supposed to contain 2,000 (rupees–that had to be taken on trust–and then multiply the number of bags and you get a crore of rupees. Like that, you count the molecules of the atmosphere. It is only a sort of estimate. But more than that, we can actually see the scattering of light simply by looking through an instrument; you can find out whether a molecule is short or long, whether it is spherical or tetrahedral shape and so on. The study of the blue sky is an immense field of research, an unlimited field of research, which was opened up and is still being pursued.

The quest, you see, is the more, the deeper you go. Then the question arises what about light? I cannot possible enter into all that, Because, my idea, as I told you, is just to give you a simple glimpse into how a familiar phenomenon is linked up with deeper problems of Physics and Chemistry. That is the lesson we learn today. From the familiar fact, it is not necessary to hunt round the text books to find problems of science. You keep your eyes open and you see that all round you the whole world bristles with problems to solve; but you must have the wit to solve it; and you must have the strength of mind to keep going at it until you get something. This is the lesson which I want to bring home to the younger generation in front of me. What is the use of all this? Here again, I want to stress the philosophy of my life. Never to ask what is the use of all this. As I told you before, it is the striving that is worthwhile. Because we have certain inherent powers given to us to use–observation and thinking–we must use them. The more

we use them, the sharper they become, the more powerful they become and ultimately something will come out of it so that humanity is benefited, science is benefited. Ultimately the aim of scientific knowledge is to benefit human life. And that comes automatically because the problems with which we are concerned in science are always those that lie nearest to hand. They are concerned with things about us. So long as we deal with the problems which arise out of our environment, you never can say that any particular piece of work can be useless. The most important, the most fundamental investigations, though at first might seem an abstraction of nature, are precisely those which in due course, affect human life and human activities most profoundly. This is a very heartening thing because one should not think that scientific work in order to be valuable, should be useful. Scientific work is valuable because it will ultimately prove its value for the whole of human life and human activity. That is the history of modern science. Science has altered the complexion of things around us. And precisely those scientists who have laboured not with the aim of producing this or that, but who have worked with the sole desire to advance knowledge, ultimately prove to be the greatest benefactors of humanity.

Appendix-VI

Scientific Outlook

(A Talk, over the All India Radio by Prof. Raman)

It is customary in all branches of science to associate the names of eminent men with the facts and principles discovered by them which form the foundations of the subjects. This practise is found to be useful since it helps to abbreviate and give precision to the terminology of science. It also serves to commemorate the name and fame of the leaders of science whose labours have helped to create the subject. Indeed, this is how the student of science first gets to know the names of the great leaders in his subject. The touch of human interest which the study of science gains in this way is of no small value, since it emphasises the real nature of science as a living and growing creation of the human spirit.

A study of the history of individual branches of science and of the biographies of the leading contributors to their development is essential for a proper appreciation of the real meaning and spirit of science. They often afford much more stimulating reading than the most learned formal treatises on science. To the teacher, such histories and biographies are invaluable. Whenever he finds the attention of his listeners flagging a little, he can always enliven his class by telling a little story of how this or that great discovery in his subject was made, or by recalling some anecdote about one or another of the famous investigators in the field. In this way, the teacher can convey to the student an understanding of how science is made and of the intellectual outlook which is the essence of it.

What is meant by a scientific discovery? How is it made? These are questions of personal interest which are often asked and

to which the most varied answers have been returned. A discovery may obviously be either of a new fact or of a new idea. It is clear, however, that an unexplanied observation is of no particular significance to science. An idea unsubstantiated by facts is equally devoid of importance. Hence, to possess real significance a scientific discovery must have both an experimental and theoretical basis. Which of these aspect is the more important depend on the particular circumstances of the case, and a rough distinction thereby becomes possible between experimental and theoretical discoveries. Rontgen's discovery of X-rays, for example, was clearly an experimental one, while Planck's equally important discovery of the quantum of action was clearly in the field of theory. The distinction between the attitudes of experimentor and the theorist is most obvious in the mathematical sciences. It is much less obvious in those sciences which rest more exclusively on an empirical foundation and in which observation of facts and thinking about facts are less easily separable processes.

The word discovery suggests a dramatic and exciting event, like finding a fifty-carat diamond in a ploughed field, for example. The history of science is indeed full of such dramatic discoveries, the drama and the excitement being particularly manifested in the personal behaviour of the scientist immediately following the event. I could tell one or two stories myself of such incidents in the life of a scientist. The classic story is that of Archimedes, who rushed into the street straight from his bath with nothing on crying "Eureka Eureka" when his famous principle of hydrostatics flashed into his mind. The point of the story is the intense emotion aroused by a sense of the overwhelming importance of the new idea. The joy and exhalation felt at such a moment are indescribable. Indeed, such dramatic moments come into the life of even the most devoted follower of science but once or twice in his career. They are the greatest reward of a life-time spent in the pursuit of knowledge for its own sake. Lesser discoveries come oftener and are a source of profound satisfaction and encouragement to the investigator. But they do not make such a soul-stirring drama.

It should be mentioned that the reception given at first to even capital discoveries by the outer world is not always of

respectful admiration. One of the commonest ways in which the achievement is sought to be minimised by the unthinking or the envious is by attributing it to accident or a stroke of luck akin to the winning of a lottery ticket. Such comments are of course deplorable and indeed quite meaningless. The idea that a scientific discovery can be made by accident is ruled out by the fact that the accident, if it is one, never occurs except to the right man. The happy discoverer in science is invariably a seeker after knowledge and truth working in a chosen field of his own and inspired in his labours by the hope of finding at least a little grain of something new. The commentators who like to consider discoveries as accidents forget that the most important part of a scientific discovery is the recognition of its true nature by the observer, and this is scarecely possible if he does not possess the requisite capacity or knowledge of the subject. Rarely indeed are any scientific discoveries made except as the result of a carefully thought out programme of work. They come, if they do come, as the reward of months or years of systematic study and research in a particular branch of knowledge.

If the world is sometimes slow to recognise the importance of fundamentally new experimental facts, it is not to be wondered at if it is slower still in appreciating and accepting new theoretical ideas. Usually such new ideas are looked upon with indifference or suspicion, and many years of persistent advocacy and powerful observational support are required before the investigator can hope to see his ideas generally accepted. The story is often told of Arrhenius and the doctorate thesis which he presented to the Stockholm University containing his new ideas regarding the nature of solution, supported by a great volume of experimental data. All that he received for this epoch-making work was a fourth-class degree permanently disqualifying him from an academic career. Arrhenius happily survived this experience, and lived to receive the Nobel Prize and to be venerated as his country's greatest scientist. But there are, unhappily, other instances of youthful genius being repressed and completely suppressed as well.

If there is one fact more than any other which stands out in the history of science, it is the remarkable extent to which great discoveries and youthful genius stand associated together. Scores of instances can be quoted in support of this proposition. Indeed, if one were to attempt to write a treatise on any branch of science in which all discoveries made by youthful workers were left out, there would be very little left to write about. The fact of the matter appears to be that, other things being the same, the principal requisite for success in scientific research is not the maturity of knowledge associated with age and experience, but the freshness of outlook which is the natural attribute of youth. The conservatism which develops with increasing age is thus revealed as a factor which militates against great achievements in science. The great ideas seem to come most easily to youthful minds. Since, however, much time is required to work out a new idea properly and fully, age and experience are not altogether useless in science. Upto a certain point, the conservation bred by age may even be useful as a brake on the wilder flight of youthful imagination. Further even the elderly may, if they so choose, retain and cherish a youthful spirit and outlook. So long, therefore, as they do not allow the conservatism of age to function as a suppressor of youthful genius the elderly may continue to find themselves useful as guides and inspirers of research. On this view, indeed, the principal function of the older generation of scientific men is to discover talent and genius in the younger generation and to provide ample opportunities for its free expression and expansion.

So far I have said little about the nature of the urge which leads the elite few to devote themselves to science and live laborious days in its service. This is a part of the larger question, what is it that drives men to devote themselves to any type of idealistic activity? I think it will be readily conceded that the pursuit of science derives its motive power from what is essentially a creative urge. The painter, the sculptor, the architect and the poet, each in his own way, derives his inspiration from nature and seeks to represent her through his chosen medium, be it paint or marble, or stone or just well-chosen words strung together like pearls on a

necklace. The man of science is just a student of Nature and equally derives his inspiration from her. He builds or paints pictures of her in his mind, through the intangible medium of his thoughts. He seeks to resolve her infinite complexities into a few simple principles or elements of action which he calls the laws of nature. In doing this, the man of science, like the exponents of other forms, of art, subjects himself to a rigorous discipline, the rules of which he has laid down for himself and which he calls logic. The pictures of Nature which science paints for us have to obey these rules, in other words, have to be self-consistent. Intellectual beauty is indeed the highest kind of beauty. Science, in other words, is a fusion, a man's aesthetic and intellectual functions devoted to the representation of Nature. It is, therefore, the highest form of creative art.

Appendix-VII

Some of Professor Raman's Sayings

1. ***Criteria for Success***

   Ambition, Courage and Endeavour have been my watchwords.

2. ***Advice to Research Scientists***

   Develop self-confidence, self-reliance and a little desire to work. Young friends do this and research will come afterwards.

3. ***On Importing Equipment for Research***

   There will be no science in India if we continue to rely on imported equipment for *research* work. I call it paying for our ignorance–nay, paying for our incompetence.

   Science can and shall advance in very simple ways. We often pay Rs. 50,000 for something we can make for Rs. 5,000. The difference we pay for our ignorance.

4. ***Memorial for Gandhiji***

   The best way for perpetuating the memory of Mahatmaji is to inculcate into the minds of the coming generation of the best teachings of Gandhiji. Each boy and girl from the primary standard to post-graduate course must be made to read the best sayings of Gandhiji–these sayings being selected suitably, according to the intellectual standards of the pupils. This would be the best and potent way of doing homage to the memory of the world's greatest man and Further of Indian Nation and is better than building memorials and erecting statues.

5. ***On the Education of Women***

   No one who is a patriot, no one who looks to the future of India can fail to be impressed by the importance of women

receiving the best and the highest kind of education. No nation of which one half was sunk in superstition and ignorance could ever hope to rise.

6. Advice to Youth

You, our young men come to the Universities and leave them to face the world...a world which may seem to be an unsympathetic harsh world. I would like to tell the young men and women before me not to lose hope and courage. Success can only come to you by courageous devotion to the task lying in front of you and there is nothing worth in this world that can come without the sweat of our brow. We have abundant human material in India. Speaking as a teacher of 24 years' experience, I can assert, without fear of contradiction that the quality of the Indian mind is equal to the quality of any Teutonic, Nordic, or Anglo-Saxon mind. What we lack is perhaps courage, what we lack is perhaps driving force which takes one anywhere. We have, I think developed an inferiority complex. I think what is needed in India today is the destruction of that defeatist spirit. We need a spirit of victory, a spirit that will carry us on to our rightful place under the sun, a spirit which will recognise that, we as inheritors of a proud civilisation are entitled to a rightful place on this planet. If that indomitable spirit were to arise, nothing can hold us from achieving our rightful destiny.

7. On Religious Life

There is no Heaven, no Swarga, no Hell, no Rebirth, no Incarnation. This belief in the existence of the next world is the greatest force against true religious life. People are likely to lead a more rational and religious life, if they believed that what really mattered was the life of today. That is also the message of science to humanity.

8. On the Role of a Scientist

The true role of scientists is the discovery of Truth, they have no concern either with the applicant or mis-application of the

results of scientific discoveries. All the same, scientists owed an obligation to society, to improve it.

9. On the Misuse of Science

Men of science are completely helpless in the matter of misuses of science. Only men like Buddha, Christ, and Mahatma Gandhi, and not scientists, could solve human problems by influencing human conduct.

10. On Atomic Power

It is my conviction that out of every 100 dollars used for developing aromic energy, 99.99 dollars would be for war and only 0.01 dollars for peace.

We Indians are a peace loving people. We want to be left for ourselves. I silently pray to God to protect us from the Atom Bomb.

11. An anecdote

Prof. Raman once saw a student of his rather depressed. On being questioned about it, the Prof. was informed that a senior scientist in UK was working on the same problem with a five kilometre. X-rays rube, while his student was struggling with a one-kilowatt tube. Quick came the remark

" Oh simple: Put a ten kilowatt brain on it.?

What others said about Professor Raman

Dr. S. Radhakrishnan

Dr. Raman was a great teacher. His knowledge was not confined to Physical Science. In this over specialised world, breadth of knowledge was remarkable. He combined highest intellectual integrity with a winning warmth of heart. His latter feature sometimes comes out in his utterances, which are delightfully free and frank. He was our most illustrious scientist, who continued for many years to guide the scientific progress of India.

Albert Einstein

Dr. C. V. Raman was the first to recognise and demonstrate that the energy of a photon can undergo a partial transformation within matter. I still recall vividly the deep impression that this discovery made on all of us, who at the time, attended the colloquium in Berlin.

C. Rajagopalachari

Let us honour C. V. Raman, one of our eminent men who has raised 'India in international status and who adds to the honour of every title or honour bestowed on him.'

Lord Rutherford

Sir Venkata Raman is one of the leading authorities in Optics, in particular on the phenomeon of the scattering light. In this connection, he discovered that the lights' colour could be changed by scattering. This had been predicted sometimes before, but in spite of search, the change had not been found. The 'Raman Effect'

must rank among the best three or four discoveries in experimental physics in the last decade, it has proved and it will prove, an instrument of great power in the study of the theory of solids.

Professor K. R. Ramanathan

Prof. Raman's scientific achievements and enthusiasm for science attracted motivated young men from all parts of the country. He trained them in scientific research and instilled self-confidence in them. When they went out into the world, they could grow on their own and create schools of research in universities or entering scientific services in Government, invigorate and improve them by research and development. Raman himself remained till the last day of his long and dedicated life, the wide-eyed child of Nature, inquisitive about all aspects and phenomena of Nature and their inner workings.

May the example and memory of Prof. Raman's life and work, his courage, his faith in young men and women, and his ceaseless quest for Truth be an inspiration to the young people of our country.

Dr. M.K.V. Bappu

Raman belonged to the restricted fold, whose members gained inspiration from the beauty of their surroundings. The blue of the ocean, the plumage of the birds, floral colours and the symmetry of crystals gave him a feeling of intense rapture, and the inspiration to ponder over their origins and characteristics. Likewise the canopy of stars as seen on a clear moonless night must have stirred the imagination of one who was so much impressed by natural splendour. Indeed in one of his writings he had described astronomy as "a heaven-born river of knowledge which flows to the earth and fertilises the fields of learning and culture".

Sir Asutosh Mukherjee

I shall fail in my duty If I were to restrain myself in my expression of the genuine admiration. I feel for the courage and spirit of self sacrifice with which Mr. Raman has decided to exchange a lucrative official appointment for a university

professorship, which I regret to say, does not carry even liberal emoluments. This one instance encourages me to entertain to hope that there will be no lack of seekers after truth in the temple of knowledge which it is our ambition to erect.

Prof. Bhagwantam

He (Raman) was a self-made man and had always set an example to his associates and students, of hard work, indomitable will and total dedication to science, which he practised during his entire life time, was so intense and so much to the exclusion of all other interests that in tune with the traditions of Indian scholarship, one would be justified in calling him a real *Rishi*. Nature was the object of his worship.

We should not fall into the trap of regarding him (Raman) as just a successful scientist like what we generally regard other successful scientists or successful businessmen and successful politicians. Men like him are not thrown up every day and if the rugged contours and sharp corners of this giant did not compromise with the soft spoken ways of the successful world, we can only describe the phenomenon by stating that "it is no reproach on Everest that one cannot play golf on it."

Prof. M. G. K. Menon

Prof. Raman showed the true humility of a scientist when he spoke about others whom he regarded highly and admired such as Newton, Rayleigh, Einstein, Rutherford and so on. Among the great men of science these stood out as towering singularities. And these were the men whom Prof. Raman hoped to emulate in some way.

Prof. Raman himself was in the line of the great classical scientists–a dwindling band. The richness of his life and of his discoveries and his outstanding qualities have covered the canvas of Indian science in dominating fashion for over half a century–a richness for which Indian science will ever be grateful.

Extracts from the diary of Prof. K. S. Krishnan for the period February 5 to 28, 1928

These extracts provide a vivid picture of the excitation of Prof. Raman during this period when he along with his distinguished collaborators, K.S. Krishnan and S. Venkateswaran was investigating, the phenomenon of "feeble flourescence" originally observed by K. R. Ramanathan in 1923. It was on February 28, 1928, that Professor Raman elucidated the phenomenon and realised its full implications. The observation was given publicity on the next day. This is the Raman Effect.

February 5, 1928

For the last three or four days, I have been devoting all my time to fluorescence. The subject promises to open out a wide field for research, since at present, there is no theory of fluorescence which could explain even the outstanding facts:

Studied anthracene vapour. It exhibits strong fluorescence which does not show any polarisation, when viewed through a double image prism, Prof. has been working with me all the time.

Recently, Prof. has also been working with Mr. Venkateswaran on the fluorescence exhibited by many aromatic liquids in the near ultra-violet region present in sunlight and the fluorescence of some of the liquids are found to be strongly POLARISED. However, in view of the fact that the fluorescence of anthracene vapour does not show any polarisation, Prof. has asked me to verify again his observations on the polarisation of liquids.

February 7, Tuesday

Tried to verify the polarisation of the fluorescence exhibited by some of the aromatic liquids in the near ultraviolet region. Incidentally, discovered that all pure liquids show a fairly intense fluorescence also in the visible region, and what is much more interesting, all of them are strongly polarised; the polarisation being the greater for the aliphatics than for the aromatics. In fact, the polarisation of the fluorescent light seems in general to run parallel with the polarisation of the scattered light, i.e., the polarisation of the fluorescent light is greater the smaller the optical anistoropy of the molecule.

When I told Prof. about the results, he would not believe that ALL LIQUIDS can show POLARISED fluorescence and that IN THE VISIBLE REGION. When he came into the room, I had a bulb of pentane in the tank, a blue-violet filter in the path of incident light, and when he observed the track with a combination of green and yellow filters, he remarked. "You do not mean to suggest, KRISHNAN, that ALL THAT is fluorescence." However, when he transferred the green yellow combination also to the path of the incident light, he could not detect a trace of the track. He was very much excited and repeated several times that IT WAS AN AMAZING RESULT. One after another, the whole series of liquids were examined and every one of them showed the phenomenon without exception. He wondered how we missed discovering ALL THAT five years age.

In the afternoon, took some measurements on the polarisation of fluorescence.

After meals at night, Venkateswaran and myself were chatting together in our room when Prof. suddenly came to the house (about 9.00 p.m.) and called for me. When we went down, we found he was much excited and had come to tell me that what we had observed that morning must be the Kramers-Heisenberg effect we had been looking for all these days. We, therefore, agreed to call the effect MODIFIED SCATTERING. We were, talking in front

of our house for more than a quarter of an hour when be repeatedly emphasised the exciting nature of the discovery.

February 8, Wednesday

Took some, preliminary measurements of the polarisation of the modified scattering by some typical liquids.

February 9, Thursday

Set up this morning the long telescope and made preliminary arrangements for observing the effect with vapours. Before the arrangements were completed, Prof. left for the college for his lecture.

In the afternoon, tried ETHER VAPOUR and it was surprising that the modified rediation was very conspicuous. Tried a number of others in quick succession without, however, the same success.

When Prof. came from the college at about three, I announced to him the result, and there was still enough sunlight for him to see for himself. He ran about the place shouting all the time, that it was a first rate discovery, that he was feeling miserable during the lecture because he had to leave the experiment, and that however, he was fully confident that I would not let the grass grow under my feet till I discovered the phenomenon in gases. He asked me to call in everybody in the place to see the effect and immediately arranged in a most dramatic manner, with the mechanics to make arrangements for examining the vapours at high temperatures.

Evening was busy and when Prof. returned after his walk he told me that I ought to tackle big problems like that and asked me to take up the problem of the experimental evidence for the spinning electron after this work was over.

February 10 to 15

Studied a number of vapours, though a number of them showed the effect, nothing definite could be said regarding the polarisation of the modified scattering.

February 16, Thursday

Studied today pentane vapour at high temperature and it showed a conspicuous polarisation in the modified scattering, we sent a note today to Nature on the subject under the title “A new Type of Secondary Radiation”.

February 17, Friday

Prof. confirmed the polarisation of fluorescence in pentane vapour. I am having some trouble with my left eye. Professor has promised to make all observations himself for sometime to come.

February 19 to February 26

Studied a number of other vapours.

February 27, Monday

Religious cermony in the house. Did not go to the Association.

February 28, Tuesday

Went to the Association only in the afternoon. Prof was there and we proceeded to examine the influence of the wavelength of the incident light on the phenomenon. Used the usual blue violet filter coupled with a uranium glass, the range of wavelengths transmitted by the blue violet filter along. On examining the track with a direct vision spectroscope, we found to our great surprise the modified scattering was separated from the scattering corresponding to the incident light by a dark region.

Bibliography

A detailed list of the published scientific paper of Prof. Raman is given in the *Biographical Memories of the Fellows of the Royal Society, London* (1971) on Chandrasekhara Venkata Raman, written by his distinguished student, Prof. S. Bhagavantam.

Prof. Raman was no narrow specialist. He had left his mark in several branches of Physics. During an active period of 65 years, commencing from a young age of 18, he published nearly 400 original scientific papers. A break-up of these papers under the different branches of Physics is given below to enable the reader appreciate the range of subjects this genius did successfully explore:

Wave Optics

46 papers during the period 1906-1959

Vibrations and Sound

23 papers during the period 1909-1922

Theory of Musical Instruments

18 papers during the period 1914-1934

Colloid Studies

9 paper during the period 1909-1927

Molecular Scattering of Light

30 papers during the period 1919-1953

X-rays, Electron Diffraction and Crystal Optics

121 papers during the period 1923-1968

Magnetism and Magneto-Optics

11 papers during the period 1927-1931

Electro-Optics and Dielectric Behaviour

6 papers during the period 1926-1929

Raman Effect

17 papers during the period 1928-1932

Viscocity of Liquids and Surface Forces

8 papers during the period 1907-1928

Ultrasonic and Hypersonics

9 papers during the period 1935-1938

Line and Band Spectra

4 papers during the period 1922-1925

Optics and Elastic Properties of Solids

25 papers during the period 1918-1959

Physiology of Vision

85 papers during the period 1959-1970

Miscellaneous

9 papers during the period 1942-1968

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Besides the above, Prof. Raman has delivered several University convocation address, radio talks, and presidential addresses at numerous scientific associations and forums in India and abroad.

Chandrasekhara Venkata Raman was the eminent physicist, whose pioneering and groundbreaking work in the field of light scattering earned him the Nobel Prize for Physics in 1930. He discovered that, when light traverses a transparent material, some of the deflected light changes in wavelength. This epoch-making discovery has become a breakthrough technology with wide-ranging potential and is used widely for security purposes.

Dr. P.R. Pisharoty, a student of Raman and writer of this book, brings forth the glimpses of the perseverant scientist amidst the trials and tribulations of his life and times. The lucid account highlights the back-breaking research, the hard work and the toils that went into transforming an Assistant Accountant General which Raman was in 1907, into a scientific colossal.

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